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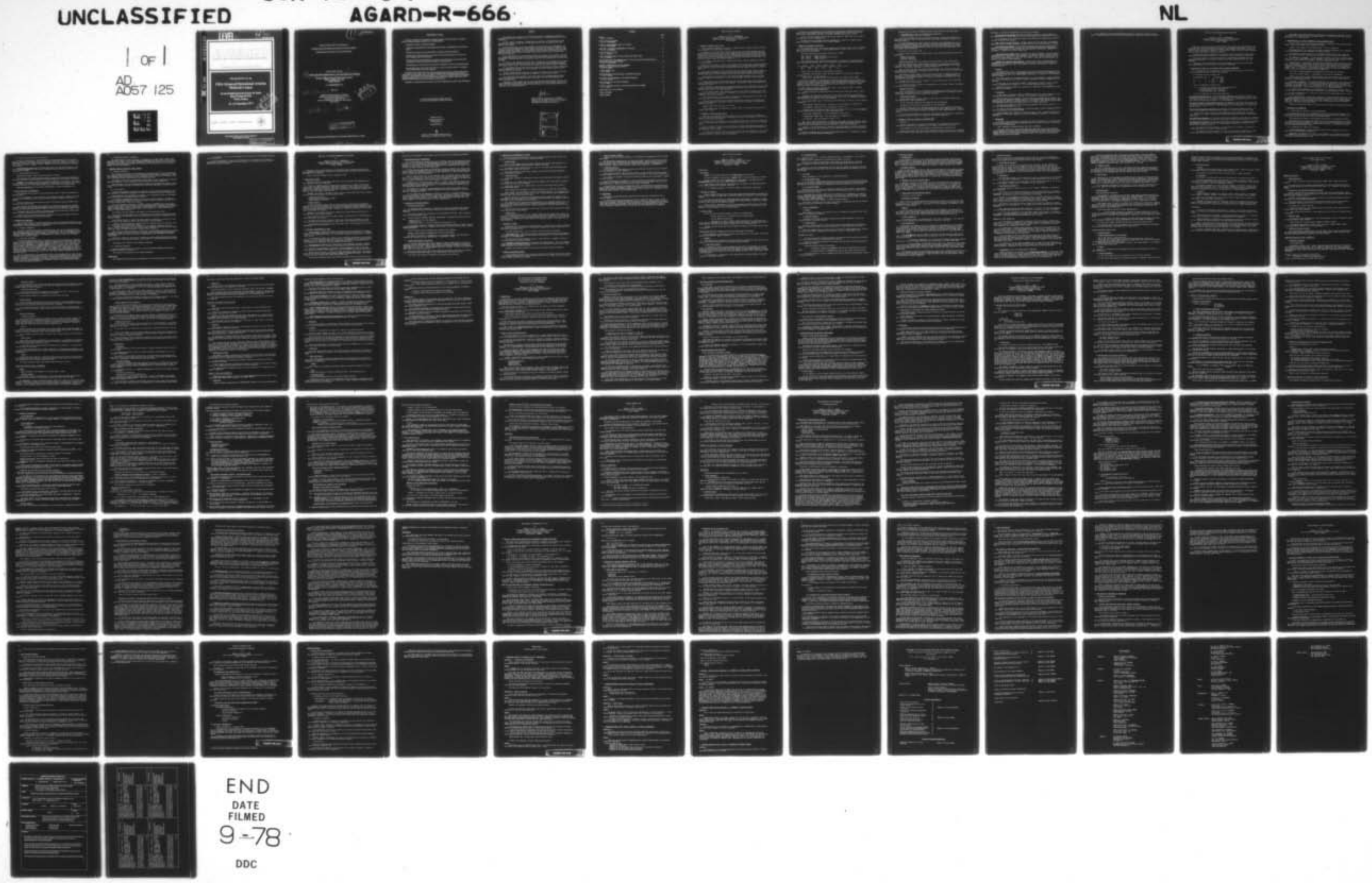

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Fifth Advanced Operational Aviation Medicine Course

Ecole d'Application du Service de Santé
pour l'Armée de l'Air
Paris, France

12–23 September 1977

NORTH ATLANTIC TREATY ORGANIZATION

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.666

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ECOLE D'APPLICATION DU SERVICE DE SANTÉ
POUR L'ARMÉE DE L'AIR
PARIS, FRANCE

12–23 SEPTEMBER 1977

Edited by

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PREFACE

The subject matter chosen for the Vth Advanced Course of Aeronautical Medicine concerns the selection procedures of the flying personnel in ophthalmology and oto-rhino-laryngology.

In fact, visual and auditory information are essential to flight safety and good completion of missions, especially in high speed and low altitude flights which meet specific requirements.

There are many types of aircraft equipped with traditional panel instruments, the reading of which requires perfect visual acuity, quick and flawless color perception and a retinal sensitivity adapted to various cockpit illuminations ; however, there are some squadrons of fighter aircraft, the performance of which requires very sophisticated information processes, using electronic display systems;there again vision is broadly used and must be efficient.

Voice communications with the ground also make for accuracy of air traffic. The auditory system must be able to perceive all data of an operational conversation in spite of the negative influence directly or indirectly exerted on the cochlea by the various flight stresses.

In addition, the speeds we can reach now, the resistance of airframes and the improvements of the control surfaces allow for great, complex and unusual duration maneuvers which among others involve the equilibration system and may cause vestibular dysharmony.

It is therefore logical that the visual auditory and vestibular fitness standards be enough differentiated to allow the flying personnel to ensure functions which are more and more difficult to perform.

Medical examinations performed at the examination centers for the flying personnel must use precise and reliable techniques to confirm or infirm flight fitness.

Such processes must preferably bring about objective and unquestionable results easier to obtain with electrophysiological techniques, like electroretinography and electronystagmography.

Therefore it seems useful that all Air Force Medical Officers become familiar with these examinations and compare them with those used in their own countries. They will so add up to their experience and improve their efficiency in the medico-physiological surveillance of the flying personnel.

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COLOR VISION IN AVIATION

by

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Paris France

1. INTEREST OF NORMAL COLOR VISION

The information presented to the pilot is mostly visual. Among all ocular functions, color perception has a particular interest.

1) Preparation of aircraft before flight requires that the flight engineers and electronic engineers have normal color vision. Tubes containing the various gases and fluids necessary for aircraft operation are differentiated by a conventional color code. Resistances used in electronic systems are not differentiated by volume or by shape but rather by color codes which are sometimes difficult to interpret when subjects with normal color vision are working under poor lighting condition.

It is easy to understand that a mistake could cause a failure potentially threatening flight safety.

2) Operation and flying of aircraft also require that the pilot has a normal perception of colors. Pilots and engineers must read information on the instrument panel, which are often colored in order to be better differentiated and thus easier to read in a shorter time.

The recent development of new information systems using cathodic screens -which are probably going to be used on a general scale- does not exclude the use of color codes. We even think that the color function will be even more used in these future systems.

Like navigators, pilots have to read navigation maps printed in color to be used by normal subjects. Any abnormality in the color perception may lead to misinterpretations.

During flight, the flight engineer may have to make some repairs, often under difficult conditions imposed by flight requirements. This problem is also very important for the Naval Air Force.

3) Air Traffic controllers must also perceive correctly the colors showing on the radar screens and cathodic tubes. Chromatic abnormalities disturb the controller, increase his fatigue and can lead to erroneous judgments.

In the control tower, the controller may have to use flares to authorize or refuse landing of an aircraft in a difficult situation, e.g. failure of the radio system, or in a specific operational situation.

Just like the pilot who will have to interpret the message given by the flare, the controller should not make any mistake in his choice.

The controller may also have to identify an aircraft as well as its direction by evaluating the position of navigation lights ; this can be a difficult task under poor weather conditions.

Weather specialists also use a color code.

These examples show the importance of color coding in aeronaùtics and the need for normal color vision.

2. INTEREST OF STUDYING COLOR VISION

What we just explained about the important role of color signals in aeronautics should be convincing enough to deter from safety oriented carreers subjects with an abnormality in their color perception.

However, this is not always so, either because subjects are not aware of dyschromatopsia, or because their motivation is so intense that they hope it will not be discovered.

1) It is therefore necessary to give subjects a thorough ophthalmological check-up at the admission visit in order to detect any known and unknown hereditary dyschromatopsia by simple and reliable tests.

In France, we discover every year that 3 % of the military candidates to the carreer of flying personnel present cases of dyschromatopsia. Such a non negligible percentage seems sufficient to justify a selection process.

2) Abnormal color perception can be hereditary and congenital, therefore practically stable for a given subject. We know that ocular or general pathological affections can be the cause of acquired unilateral or bilateral abnormalities in color vision.

It will then be necessary, during the control visits, to check each eye for possible detection of such an abnormality.

We believe that this severe selection implemented in France is a safety warrant which contributes to the decrease in air traffic hazards.

3. NORMAL AND ABNORMAL COLOR VISION

1) The normal subject can only identify spectral colors which account for only a small part of the radiating energy : they range between 380 and 780 nm (1 nm = 1 m μ = 10 Å = one billionth of a millimeter).

The color spectrum can be roughly divided into 3 bands :

380 - 500 nm : purple and blue
500 - 600 nm : green, yellow green and yellow
600 - 780 nm : orange and red.

The ultra-violet light and the infra-red light are respectively located on either end of the spectrum. Neither light can be perceived by the eye as a visible radiation.

UV	Purple	Blue	Green	Yellow	Orange	Red	IR
	380	440	500	570	600	610	

These colors are defined by three physical parameters :

- luminance (non chromatic factor defining a quantity of light with respect to a surface) ;
- wave length, i.e. periodicity ;
- purity, i.e. quantity of white light mixed with the dominant wave length.

2) It is not possible to study here all the theories pertaining to color vision. It is sufficient to know that the trichromatic theory (whether three types of photo-receptor cones or three types of sensitive pigments) offers an explanation to practically all disorders of color vision which are found mostly in male subjects (8 % approx.), women *being only carriers of such disorders.*

3) This theory is based on three primary colors : red, blue and green. It permits classifying hereditary dyschromatopsias.

- Subjects who have a normal perception of these three colors are normal trichromats (92 %).

- Subjects with poor color perception or with a level of perception varying with time (especially as a function of the conditions of observation) are abnormal trichromats. This group can be divided into three sub-categories :

* protanomaly (HART type) : deficiency in the perception of RED (10 % of all dyschromatopsias)

* deuteranomaly (RAYLEIGH type) : deficiency in the perception of GREEN (59 %)

* tritanomaly : deficiency in the perception of BLUE (1 %).

- Subjects who do not perceive one of the three primary colors are called dichromats. This group can also be divided into three types exhibiting :

* protanopia (DALTON type) : lack of perception of RED (10 %)

* deuteranopia (NAGEL type) : lack of perception of GREEN (14 %)

* tritanopia : lack of perception of BLUE (1 %).

Most often, these abnormalities are isolated in the same subject and equally affect both eyes. They do not vary with time, although dyschromatopsia increases with age (a decrease in color discrimination can also be observed in older normal subjects).

Finally, it is not impossible to observe in the same subject an acquired dyschromatopsia which can account for a variation of an already known disorder or for its reinforcement.

4) There are numerous types of acquired dyschromatopsias and it is impossible to match them exactly with hereditary dyschromatopsias.

According to the theory of KOELLNER we shall divide them into two major types :

- a RED/GREEN type, close to protanopia and deuteranopia ;
- a BLUE/YELLOW type, close to tritanopia.

In clinical examinations, the first type of disorder is essentially observed in cases where the optic nerve is affected and the second type of disorder in cases of chorioretinal damage.

Such dyschromatopsias may vary, either in the sense of an improvement or in the sense of further deterioration. They can affect both eyes differently and are practically always followed by a decrease in the visual acuity and a perturbation of the visual field. These characteristics differentiate them from hereditary dyschromatopsias which are usually isolated disorders.

5) Variations in the color vision

Certain complex components can modify color vision. We shall group them into three categories :

- spatial variations
- temporal variations
- extrinsic variations

Spatial variations affect the stimulus size and position in the visual field.

When the stimulus size increases beyond the usual 2°, saturation and luminosity increase, then diminish beyond 20°. A subject exhibiting dyschromatopsia for a visual field of 2° can become a trichromat in a visual field of 10°.

When, on the other hand, the stimulus size decreases, the colors are then less accurately perceived and vision becomes dichromatic under 15 min of arc : we then observe a case of foveal tritanopia.

The position of the stimulus in the visual field is also an important factor. A decrease in color perception can be observed in the periphery, which degenerates into achromatopsy on the outside periphery. In reality, if sufficient intensities are used, the colors are perceived.

"Normal color vision" is thus reduced to a limited pericentral circle which does not even cover 10 % of the retina.

All these facts must be taken into consideration in the design of panel instruments as well as control consoles.

Temporal variations

The actualization of the color sensation requires a certain latency. This is why variations can be observed in the interpretation of ISHIHARA'S test according to the exposure time. Flashes still raise controversial problems.

Extrinsic variations

Miosis (pathological or drug induced) of more than 2 millimeters induces lower color perception, a real "mesopisation".

On the other hand, mydriasis can improve certain performances.

Refraction has practically no influence on color perception.

On the contrary, age is an important factor. Color vision changes continuously over the years. It seems to be at its maximum between 30 and 40 years and then decreases. It is then necessary to always interpret the results of color examinations as a function of age.

All these variations must be taken into consideration when deciding of a subject' s fitness and in order to improve -if possible- the working conditions.

4. SYSTEMATIC CHECK AND DIAGNOSIS OF ABNORMALITIES

1) Methods

As far as selection and fitness are concerned, it is essential to know whether the exhibited abnormality is compatible with a safety oriented activity or not.

The diagnosis of the type of abnormality is delivered in a second step.

We can use various tests which can be divided into four categories. It is necessary to combine several tests, then apply tests of different categories to establish a precise

diagnosis, to quantify the abnormality and follow its evolution.

The discrimination methods are based on a common principle : color confusion in the interpretation of plates gathered in an album by subjects with abnormal color vision.

It is necessary to use these test plates in pre-defined and reproducible conditions in order to obtain valid results.

Many tables have been proposed : the most widely used are the tables of ISHIHARA, HARDY RAND RITTLER, BOSTROM KUGELBERG, DVORINE and those of the American Optical Company.

The denomination methods are very useful. They use lanterns with colored lights emitted at wave lengths used in aeronautics. The presentation speeds and surfaces can be varied ; the importance of these factors has been mentionned previously. FARNSWORTH's and BEYNE' s lanterns are the most widely used.

The equalization methods permit diagnosing the type of disorder. In France, NAGEL's anomaloscope is the most widely used instrument. It permits differentiating the protan and deutan axes by calculation of the RAYLEIGH equation (Red + Green = Yellow). The normal quotient ranges between 0.65 and 1.3. It is lower in the case of protanomalopia and higher in the case of deuteranomalopia.

Methods for comparing classification. The most widely used of these methods are FARNSWORTH'S 15 and 100 Hue tests which make it possible to objectivate the axis of the disorder and to quantify it. It is thus possible to follow the evolution of acquired dyschromatopsias.

2) Results

The examination of color vision regarding the fitness of flying personnel rests on a discrimination process and on a denomination process. In France, we use ISHIHARA's test, presented under the light of an EASEL-MACBETH lamp placed at a distance of 70 centimeters from the subject.

This test reveals 98 % of dyschromatopsias. It is not designed to reveal abnormalities in the blue/yellow axis and does not permit establishing a precise diagnosis of the disorder.

If this test is not conclusive, BEYNE's chromoptometric lantern is used. Colored lights are presented at 5 m under a 2' of arc angular aperture during 1/25 sec.

Diagnosis of dyschromatopia can potentially be established using FARNSWORTH's tests and NAGEL's anomaloscope.

3) Standards

If the subject interprets correctly ISHIHARA's plates, his color perception is considered normal and coefficient 1 is given to his Aviation Color Standard (ACS).

When the subject makes mistakes, the ACS/2 profile is proposed and the subject must identify the light signals of BEYNE's lantern. If the subject gives several correct interpretations, profile ACS/2 is then maintained but if he makes a single mistake profile ACS/O is established, which makes the subject unfit for all flying activities.

The same method applies for civilian flying personnel, but with an angle of 3' of arc and a stimulus exposure of 1 sec.

In case of acquired dyschromatopsia, the flying person is declared unfit during the period of evolution of the causal disease.

If the subject fully recovers, he is declared fit. If not, a special authorization may possibly be delivered, taking into account the experience acquired in the field of aviation.

5. CONCLUSIONS

The role of color perception in aeronautics, which we underlined in the first part of this exposé, seems to be a very sufficient reason to justify the policy of systematic detection of dyschromatopsias.

Such a procedure certainly reduces the risk of accidents.

As a last word, let us recall that there is no medicine or drug and no physical system capable of correcting hereditary dyschromatopsias. Even though affected subjects may not experience any difficulty during their ground based studies, their condition may involve a risk in a flight situation, which can lead to hazardous misinterpretations, potentially the cause of accidents.

Color perception of flying personnel must now and in the future be taken into account for selection purpose as future cockpit systems will always rely upon color coding.

VISION AT LOW LUMINANCE LEVELS IN AVIATION

by

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There are only some aviation activities which are carried on in the day-time, thus in the photopic field which sometimes involves high luminances. Night flight involves low luminances, with the use of special instruments, under specific conditions, in order to obtain a better performance, especially in helicopters. Outside vision is always necessary for the pilot during flight, landing or taxiing.

Low luminance vision is related to rod activity under low intensity light stimuli which produces a message transmitted to the occipital cortex through the optical path.

The visual capacity is also the expression of psychosensory processes which are produced and modulated in the superior centers during the interpretation of the light sensation.

Therefore, training and repetition of low luminance activities may bring about better performances in facilitating the integrative phenomena.

1. DEFINITION OF LEVELS OF ILLUMINATION FROM A PHYSICAL STANDPOINT.

1.1 - Illumination units are different in the different countries and vary according to the authors and this is sometimes very confusing.

It is almost useless to remind that :

O logarithmic unit	=	1	simple	unit
1 " "	=	10	"	units
2 " "	=	100	"	units
$\bar{1}$ " "	=	0,1	"	unit
$\bar{2}$ " "	=	0,01	"	unit

But it is important to repeat that :

1 nit = 1 cd hm^2 = 8 picostible log-units (psb log.units)
= 0.5 apostible log.units (asb log.units)
= 1.5 Micro-Lambert (M.L. log.units)
= 4 log.stible units (sb. log.units).

It is also necessary to review some definitions :

Gross light threshold (G.L.T.) is the elementary expression of the visual function. It corresponds to the ability to perceive the lowest possible light stimulus. If the intensity of the stimulus is too low, there is no perception ; if it gradually increases, a certain level of perception is attained : it is the threshold.

The absolute terminal light threshold (A.T.T.) corresponds to the lowest light the retina can perceive when it is adapted to total darkness. When the whole retina is concerned, it is the general threshold (A.T.G.T.), when only part of it is concerned, it is local threshold (A.T.L.T.).

The relative and absolute thresholds are function of the selected adaptation level, i.e. of the time necessary for the eye already blinded by a strong light to perceive them.

One must not confuse the gross light threshold with the differential threshold, which makes the eye able to perceive the smallest light difference between two contiguous light areas.

The morphoscopic threshold is the ability of the eye to perceive a form, and not a quantity of light. The threshold is the smallest light quantity which allows recognition of a form.

The morphoscopic threshold is less physiologic than the other ones. It presents a practical and ergonomic interest. It precedes the cinematographic threshold also described here, which allows movement detection.

1.2 - The photopic field corresponds to a good natural or artificial illumination, it is day-time vision. It is above 7.5 psb log.units.

The scotopic field corresponds to a very low illumination, comparable to night vision when there are no moon or stars. It is as low as 4.1 psb log.units or less.

The mesopic field ist between the two others and corresponds to day-break. It can be divided into two sub-fields : high mesopic field i.e. 6.3 psb log.units and low mesopic field i.e. 5.3 psb log.units.

2. CHARACTERISTICS OF VISUAL INFORMATION AT LOW LUMINANCE LEVELS.

We must admit that from a practical standpoint low luminance vision presents advantages, since it only needs a small quantity of light.

However, this economy is counterbalanced by a loss of information.

The sensitivity of the normal eye can reach a maximum corresponding to a luminance 10,000 times weaker than that necessary for photopic vision.

The adaptation occurs slowly but is not exactly proportional to time, since the absolute terminal threshold is practically obtained by the 20 th minute of adaptation.

The adaptation is fragile : if the luminance increases, part of the acquired adaptation is lost which accordingly delays attainment of the threshold. When a source of high intensity causes a glare for the subject, the whole adaptation is lost.

Visual acuity is significantly reduced, because adaptation occurs especially in the rods, which need only a small amount of energy. But if the peripheral rods are numerous, they are less numerous in the center of the retina and there are none in the center of the macula. This corresponds to a diminishing visual acuity from the fovea toward the periphery. There is, therefore, a physiological central scotoma at very low illumination levels, which can be objectively measured with campimetry.

The sense of depth perception and movement is also changed and disturbed.

Color vision whose support is represented by the cones also disappears.

Finally, the central scotoma (whose intensity and surface change in parallel with the level of adaptation) changes the central visual field of 2°30' and the peripheral field of 30° on the temporal side.

The sense of contrasts : the PURKINJE phenomenon. The peripheral retina does not differentiate color tonality but is sensitive to the relative brilliance of the different tonalities. In photopic vision, the green/yellow (500 nm) appears as the brightest, but in mesopic and scotopic vision, it is the green/blue (510 nm) which appears as the brightest. The displacement in the maximum sensitivity is the PURKINJE phenomenon.

In studying this phenomenon, we understand how it is possible to confuse colors located under or above the 550 nm band, which cannot be differentiated by their tonalities.

We also understand why it is useless to select blue for camouflage since it is the easiest color to perceive.

The convergence focus of Green/Blue radiations is located slightly before the layer of photoreceptors (whereas the Green/Yellow radiations focus exactly on the retina of emmetropic subjects. In these scotopic conditions, a myopia of 1 to 1.5 diopter appears which still reduces the visual performance, since the convergence focus of Green/Blue radiation is far before the retinal plan.

These are the characteristics of the visual function under low luminance conditions.

3. VARIATIONS IN INFORMATION.

3.1 - Variations as a function of ocular parameters.

The iris plays the part of a diaphragm and according to the pupil diameter, lets through more or less light, which changes the retinal illumination. The thresholds rise as the pupil contracts, and the visual field becomes smaller.

This explains the effects of pilocarpine instillations in glaucomatous subjects.

The past history of the eye also plays a part. The visual performance is different for subjects who have been exposed to a strong light in the few hours preceding a flight and those who have been exposed to a dimmer light. Therefore, we understand the importance of preadaptation before flight.

3.2 - Variations as a function of stimulus.

Colored preadaptation is characterized by the fact that radiations above 650 nm (Red) do not cause retinal disadaptation.

Adaptation also depends on the color of the stimulus. It is therefore interesting to maintain a red illumination in the cockpits, because it allows lower visual performance while preserving outside vision.

3.3 - Inter and intra individual variations.

Overnight fluctuations in the performance of the same subject are not important. However, the age of the subject causes a rise of the thresholds, about 0.10 log.unit for each decade. This rise has been attributed (WEEKERS, 1958) to a progressive diminution of the pupilla diameter. Fatigue is also a negative factor which disturbs the psychosensory analysis.

Interindividual variations have always been noted. They are more important in the first minutes of adaptation ; the terminal thresholds remain practically identical but the speed is different.

3.4 - Flight related variations.

Beside these changes, some others are specific to flight.

The importance of oxygen has been proved by studies of the biochemical phenomena of vision and studies of the transformation of chemical phenomena into electrical phenomena.

Anoxemia, for instance, disturbs low luminance adaptation. The rods are very sensitive to a drop in the oxygen partial pressure. At 5.000 meters (16.500 feet), night vision is reduced by about 45 %. The climbing speed must also be taken into consideration.

Noise and vibrations can also reduce performances, as shown by MERCIER et al.

4. USE OF THIS MODE OF INFORMATION.

Low luminance vision occurs on the ground during taxiing, take-off and especially during landing.

If it is impossible to use projectors for operationnal reasons, landing may become difficult for helicopters as well as for aircraft, because altitude is difficult to assess.

Ground collisions with other planes or ground installations may be caused by bad vision at such light levels.

During flight the informations provided by the instrument panel must be carefully watched to control the plane and simultaneous outside vision is necessary to watch the position of other planes during patrol flight or to detect the presence of another plane.

Outside vision is also necessary during high speed and low altitude flights, when there is neither automatic pilot nor terrain following.

Outside vision is finally required in helicopter low altitude flights if there is no brilliance amplificators (using infrared light).

5. NECESSITY FOR SELECTION.

For all these reasons, it appears necessary to select the subjects according to their low luminance vision. This will be a clinical and functional selection and the results may be checked by an electrophysiological examination.

5.1 - Clinical standpoint.

In order to discover abnormalities related to poor vision at low luminance levels, the subject will first have to answer a set of questions and, what is more important, undergo an ophthalmoscopic examination through a dilated pupilla. We can thus detect partial albinism, Oguchi's disease, retinal heredodegeneration tapetum of which the pigmentary retinopathy is a typical example.

5.2 - Functional standpoint.

The BEYNE's scoptoptometer makes it possible to measure the morphoscopic threshold after a 20 mn preadaptation period, which involves form recognition. The normal value measured with this instrument is 0.12 cd per square hectometer for a 20 year old subject. We can also use the adaptometer of GOLDMANN WEEKERS to derive a typical curve from the subject's answers. This curve has 2 segments which meet at an angular point called "alpha point" at the 5th mn of the examination. The first segment has a steep slope for the first minutes and after the 5th mn, remains stable : it represents the cone adaptation curve. The second segment of the curve first shows a steep slope, then a mild slope and the threshold is practically obtained about the 25th mn. The second segment represents the rod adaptation curve.

This is an accurate but long examination, which cannot be performed for each subject. Moreover, if subjects with a deficient night vision can be eliminated if the value of their absolute threshold is insufficient, this type of measurement does not permit selecting the subjects with the best low luminance efficiency, whereas the scotoptometer makes such a selection possible. The adaptometry curve completely neglects the psychosensory element ; it only gives a perception threshold.

5.3 - Electrophysiological standpoint.

Two examinations are used to confirm, if necessary, bad night vision. We will discuss them later. There is on one hand electroretinography, a process which allows, during adaptation, the study of the b.2 wave representing the scotopic activity of the retina and on the other hand, electrooculography for the study of the rest potential of the retina adapted to light and darkness.

6. RESEARCH AIMED AT IMPROVING VISUAL COMFORT.

6.1 - Working conditions.

The engineers who design the instrument panels -sometimes with the help of physicians- are trying to improve the visual aids. The legibility of instruments is improved by a change in graphism and by improving the inner or projected light by the use of rheostats. They try to eliminate harmful reflexions and avoid blinding sources.

An attempt is also made at improving the radar rooms. We try to preserve the contrast screen/environmental light. Relaxation rooms are designed to improve adaptation.

The development of brilliance amplifying processes should improve this type of vision. Such efforts are not negligible and have led to a definite improvement of working conditions.

6.2 - Drug research.

All medicines proposed to improve low luminance vision should be discussed not only with reference to subjective impressions but above all assessed by objective examinations.

The morphoscopic and adaptometric thresholds will be examined as well as the mesopic visual field and the electrophysiological criteria.

VON STUDNITZ, HAMBURGER and MONJE have shown that heleniene (Adaptinol BAYER) has an effect on immediate adaptation. It has to be used for about 10 days, at the dose of two to four lozenges a day to give a good result.

The Anthocyanosides (Difrarel 100 CHIBRET, Nigrantyl FOURNIER) have been studied by many authors both from a biochemical and electrophysiological standpoint. These products improve visual comfort, reduce visual fatigue, lower adaptometric and morphoscopic thresholds, and prematurely raise the amplitudes of the scotopic E.R.G. Their effect lasts, however, a short time (48 hours).

One cyanidin (Nyctalux DULCIS) also seems to give interesting results.

The study of the drug effects is not therefore without interest. The molecules which may be involved in the biochemical cycle of the scotopic vision must be studied and their effects compared.

The processes likely to improve the psycho-sensory conditions are, above all, based on training for low luminance vision. They are based on two principles :

- making the flying personnel conscious that low luminance vision is deficient (acuity, visual field, color sensitivity, glare) ;
- teaching how to give a better response in low luminance conditions and how to obtain a better interpretation of the received sensory messages. Forms can be better appreciated by simple and speedy techniques (contrast study, scanning).

Such training can be practised in a dark room, with instruments projecting on a screen motionless or mobile pictures at mesopic or scotopic luminance (instrumentation designed by PERDRIEL, BRICE and COLIN at the Centre d'Enseignement et de Recherches de Médecine Aéronautique).

With such a technique, the subject's capacities under low luminance could be quickly restored after a flight interruption due to an accident or an anergic disease like influenza.

The results are a function of the number of sessions.

6.3 - Protection Research.

Since low luminance vision is fragile, it will be quickly changed by glare and it is therefore important to protect it.

This aspect of the problem will be studied separately.

CONCLUSIONS.

Low luminance vision does exist in aeronautics, on the ground as well as in flight.

It is important to have a good knowledge of its limits and of the changes affecting visual information.

It is also important to know its variations and to be informed of the medicinal or psychosensory possibilities to improve the performance in this type of vision, which is particularly labile and fragile.

GLARE AND ITS ADVERSE CONSEQUENCES IN AVIATION

by

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Adaptation of the visual system to low luminance levels -which we described in a previous session- can often be destroyed in the aeronautical environment and thus deprive the subject of its benefits.

Glare is the most frequent cause of adaptation loss.

1. DEFINITION OF GLARE.

The word "glare" is very widely used, but in fact its causes and consequences are only beginning to be well understood.

1 - Glare is a temporary loss of visual acuity, connected to a change in the central visual field, reversible immediately (seconds or minutes) or over a long time. In the second case, the image of the bright light source persists on the retina for several hours, leaving a post image which creates a functional disturbance, the magnitude of which depends on the source surface and intensity.

SHAPERO's dictionnary, compiled in 1968, lists 10 factors which can be glare sources. In fact, they can be divided into three major factors :

- sensory disturbances ;
- deterioration of the optical image ;
- psychological disturbances.

2 - Sensory effects :

Sensory disturbances appear when the light intensity exceeds 1000 feet/lamberts. Between 7 and 10,000 feet/lamberts tearing and eyelid spasms are constant symptoms if the cause of the glare phenomenon persists. Visual acuity decreases rapidly although the quality of the retinal image is not altered. In theory, it should even be better since the surface of the pupilla is reduced.

However, a veil effect occurs which reduces the contrast between objects and, in the same time, the visual performance.

The decrease in visual acuity and depth vision is associated with a disturbance of color vision and visual field.

This shows a functional disorder of the retina, which can be reversed in no less than a few days when the blinding effect comes close to the threshold of retinal burn.

3 - A psychological disturbance called "discomfort glare" is associated with the above phenomenon.

2. FUNCTIONAL CONSEQUENCES OF GLARE.

1 - Visual acuity is deeply perturbed as the subject can no longer pursue his activities. It is especially important to know the subject's resistance to glare, or to express it better, his "recuperation time", i.e. the time he requires to recover total or partial visual acuity.

The "recuperation time" is a function of the intensity and duration of the blinding flash, i.e. of the energy absorbed by the retina. It also depends on the location of the blinding source in the visual field and of the angle at which it is perceived, as well as of the anterior adaptation level and diameter of the pupilla.

2 - Color vision is impaired like visual acuity and is gradually recovered. Recovery is all the more rapid as the intensity of the source observed after blinding is high.

3 - The central visual field is disturbed in the same manner as visual acuity and color perception since it is the support for these two parameters of the visual function.

However, after recovery, we notice that the sensitivity remains lower. This phenomenon can be observed using static perimetry (HARMS or FRIEDMAN instrument). This condition can last for several hours, maybe even several days.

This threshold disensitization also affects the whole retina, and particulary the

areas which are contiguous to the central area by the action of a sideration phenomenon.

3. ELECTROPHYSIOLOGICAL CONSEQUENCES.

As we have defined the recuperation time or recovery time for the functional effects of glare, we can also define the time necessary for recovery of the electrophysiological activities of the visual system. Electroretinogram (E.R.G.) has been particularly well studied : it must recover its morphological characteristics, amplitudes and temporal characteristics before recovery can be established.

In fact, glare is associated with biochemical phenomena affecting the retina. They produce electrical phenomena which affect the paths and relays of the visual message and also the primary and associative projection areas. Changes in the visual evoked response (V.E.R.) account for such disturbances.

The "b_1" wave of the E.R.G. is the component with the fastest recovery. Recovery of the "a" wave is faster than that of the "b_2" wave. This *confirms the data obtained when* the E.R.G. is recorded with constant stimuli during adaptation to darkness. The amplitude of "b_2" actually increases in the normal subject as a function of time.

Paradoxally, it is possible after a glare, to record a very slightly altered V.E.R. on the primary projection areas whereas the E.R.G. or even the activity recorded on the geniculate body is still deeply disturbed. It is therefore difficult to define exactly the recuperation process involved.

The combination of electro-and psychophysiological methods for primate studies, which are difficult to implement, permits comparing the acuity recuperation level with the E.R.G. recuperation level.

It thus seems that the appearance of waves "b_1" and "a" in primates corresponds, during the post-glare recovery period, to the vision thresholds, at least if the luminance of the task approaches 0.5 Nit. At this moment only, for an equal vigilance level, the general latency of the primary V.E.R. as well as the amplitude and the time lag of the first component are close to the control V.E.R. (COURT et al.).

4. VARIATIONS IN THE MODIFICATIONS.

1 - Functional variations

a) Interindividual variations : at the same age and with the same visual acuity there are differences among individuals exhibiting no ocular pathology or refraction disorders.

It is usually agreed that resistance to glare decreases with age : this is particularly true past 40 years of age.

In young subjects *(MERCIER, PERDRIEL, CHEVALERAUD)*, recuperation has been found to be :

. excellent for 30 % of the subjects ;
. normal for 60 % ;
. insufficient for 10 % (and even definitely abnormal for 5 %).

b) individual variations : numerous factors can decrease resistance to glare. First, refraction disorders. They often disappear after proper correction and the subject recovers normal resistance.

Acute or chronic retinal diseases also influence this parameter.

Fatigue, lack of sleep and tobacco also have adverse effects.

The effect of alcohol is controversial : at low doses, alcohol could potentially increase the recuperation rate, probably by its vasodilative effect.

2 - Electrophysiological variations

In a certain number of cases, after exposure to very intense glare, an initial increase in the "b_1" wave amplitude could at first be observed, followed by a drop in the amplitudes of the "a" and "b" waves. Such a change was sometimes followed by a morphological change in the E.R.G., with disappearance of one or several "e" waves. This condition could last for as long as one month.

This would tend to prove that without affecting the fundus, there can be a reversible and long-term electrical change in the visual system after glare exposure.

This raises the problem of underlying ultrastructural alterations.

5. CONDITIONS AND CONSEQUENCES OF GLARE.

In the aeronautical environment, there are numerous causes of glare, both in the air and on the ground, during the day as during the night.

1 - Natural glare

The sun is the typical source of glare, whether the aircraft flies towards it or comes out of a dark clowdy area and enters an area of clear sky.

In acrobatic flight configurations or in air to air combat, the aircraft may suddenly find itself flying into the sun.

An aircraft flying at night can be cought in an electrical storm and lightning glare will disturb the pilot.

2 - Artificial glare

An aircraft (airplane or helicopter) flying at low altitude can be cought in search light beams.

Coming out of a clowdy area, an aircraft can suddenly find itself above a brightly illuminated area (big city for example).

An aircraft can fly over a combat zone lit up with flares and tracer bullets or cross searchlight beams.

Flare release for photographic or beaconing purposes can create the same problem.

Near a combat zone, an airfield, a plane or helicopter-carrier, it is possible that a group of aircraft are waiting their turn to land : anti-collision lights -especially if they are white- can be the source of glare.

While an aircraft is taxiing, even though the landing lights are turned on, the brightness of the runway and airfield lighting systems can disturb the adaptation process and hinder the pilots' maneuvers on the ground.

This phenomenon will be particularly reinforced if, for technical reasons, the landing lights have not been turned on or if their use has been prohibited for tactical reasons and the runway lights have been turned on suddenly in the later phase of the landing operation.

Finally, the visual performance of air traffic controllers can be impaired by sudden glare when observing radar scopes.

3 - Atomic glare

The luminous calorific effect of a nuclear weapon can also induce glare during the day as well as during the night. If the explosion is directly observed (at a distance sufficient to avoid burning) the glare effect will persist for a long time. If only the retinal periphery is affected or if glare results from diffuse radiation, the effect will be less pronounced.

6. SELECTION - TESTS.

Considering all the above mentionned phenomena, it seems useful to select candidates as a function of their sensitivity to glare and to systematically check them later on at each follow-up medical visit.

For these examinations, we use a clinical test and a special instrument :

1 - BAILLIART's test : this test is based on the study of the amount of time necessary to recover visual acuity measured before macular glare caused by a 30 second exposure to the beam of an ophthalmoscope.

This test gives rather imprecise results, often difficult to reproduce because of voltage variations and escape reflexes.

2 - COMBERG's recording nyctometer is based on the same principle, but with automatic sequencing and curve recording. We can argue that this instrument functions with a glare effect extending over several minutes.

However, the results obtained can be used for candidate selection purposes.

7. NEED FOR PROTECTION SYSTEMS.

It is illusory to believe that an action can be taken to temper the sources of glare. It is therefore necessary to try and accelerate recovery of the visual acuity and particularly consider eye protection systems.

1 - Ways to improve recovery

Ametropia must be corrected whenever it is necessary and compatible with the occupational task.

Pharmacodynamic substances must be found and studied, which can accelerate recovery of visual acuity. Some vasodilatators and anthocyanosides currently seem to achieve this result, but their action is short and they would have to be used on a permanent basis to work efficiently, which is inconceivable, except under exceptional circumstances.

2 - Protection devices

Tinted glasses are used against sun glare but they must be such as not to interfere with the reception of visual information.

Such glasses cannot be used for night flights. If the aircraft flies into a storm, it seems advisable to turn on antiflash lights in the cockpit so as to avoid disadaptation.

In a nuclear environment, two types of protective devices can be considered : passive or active devices.

The active devices are composed of various components which darken as soon as they are exposed to the luminous thermal flux ; as soon as the flux decreases they return to their former state. These devices are currently being developped.

The passive devices have a transmittance which is established by the manufacturing process. They achieve a compromise between eye protection and aircraft operation requirements. They are most often neutral filters. To use them at night, it is necessary to plan additional light sources on the instrument panel.

8. CONCLUSIONS.

The study of glare has become of particular interest with the potential use of nuclear weapons.

As they know the serious consequences of even a temporary loss of visual acuity, doctors try to select the subjects who are the most likely to withstand glare. In cooperation with engineers, medical services have developed reliable protection systems compatible with the task to be achieved. These systems have been experimented and the quality of protection tested both from a functional and electrophysiological standpoint.

DEPTH VISION IN AVIATION

by

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INTRODUCTION

1. Definitions

. DEPTH is the distance separating the blackground from the surface.

. It can be compared to the notion of RELIEF, which is what protrudes on a surface.

. VISION or depth and relief PERCEPTION are both related to the appreciation of DISTANCES separating a point from a plane chosen as reference.

. Depth vision finally permits recognizing that two objects are separated from one another under monocular or binocular conditions.

. It is a complex perception, for which a number of factors are significant.

2. Interest in aviation

. Being a highly differentiated visual sense, depth evaluation makes it possible for a man to locate himself in space and to adjust his behaviour according to the surrounding objects.

. For the pilot who works in a three-dimensional environment, it consists in appreciating aircraft altitude and speed, evaluating the distance between himself and a target as well as the relief of the overflown terrain.

. Depth vision is necessary for the flying personnel when doing critical and quick maneuvers with accuracy and safety, when the use of instruments is insufficient or inefficient, in high altitude or in low altitude flights.

3. Field of study

. We do not take the depth problems in space into consideration.

- Orbital rendez-vous and docking with the command module.

- Out of spacecraft maneuvers.

- LEM landing for which, however, depth evaluation is critical when there are no spatial landmarks, in a highly contrasted light environment, or when approaching an unknow terrain, the horizon and relief of which have never been seen before.

. However, we will extend the notion of depth in aviation to the more general field of aeronautics.

CIRCUMSTANCES WHERE THE PERCEPTION OF DEPTH IS SIGNIFICANT IN AVIATION.

Depth perception is significant in some flight phases and on the ground, for special missions and different types of aircraft.

1 - Landing

A bad appreciation of HEIGTH in the final phase is considered by many authors as the cause of 60 % of the accidents occuring during the landing phase.

a) High speed landing :

- In round-out, a single or multi-engine aircraft flies at high speed, on a steep slope, and with a nosed-up attitude. The front visual field is reduced because the aircraft nose prevents the pilot from seeing the horizon. He must therefore assess the depth by looking out the side windows with quick eye movements without ever losing sight of the instrument panel.

- In bad weather, the maneuver is more complicated for planes landing on aircraft carriers in the Naval Air Force.

b) Low speed landing :

- S.T.O.L. and V.T.O.L. aircraft, helicopters have, on the opposite, a very low approach speed, if any.
Depth vision is indicated in a direction very close to vertical.

- These are 2 conditions which make a spot landing or the choice of a "DZ" more difficult, especially when the engine flow or the rotor wash raises clouds of dust or snow.

Therefore, the final landing phase, when the aircraft touches the ground, is most of the time very critical. Vision control and an acute depth perception are necessary for precise landing.

2 - In flight

Visual information is still essential to evaluate distances.

a) In high speed flight :

It is the case for hedge hopping when the pilot must, under very difficult conditions, maintain the altitude or adjust it to the slope of the terrain and to the overflown relief. Any failure in his depth perception endangers his safety and completion of his mission.

b) In low speed flight :

Winching from an helicopter or transport by helicopter occurs close to the ground, in the turbulence zone and in hovering. Deficient depth perception does not permit precise maneuvers or difficult rescues.

- Instruments are not very useful when two aircraft fly in formation or in case of flight refuelling. They respectively move in all directions at a very slow pace. In order to keep a fixed distance between both aircraft, the pilots must keep the flight and engine controls under constant operation.
Here again, efficiency depends on accurate depth perception.

In any case, the pilot can only rely on his vision to appreciate quickly the distance separating him from a motionless or a mobile landmark.

3 - Other circumstances

a) Firing :

Every sequence of firing, air-surface, air-air or surface-air, especially with light weapons, involves depth perception.

b) Parachute-jumping :

Distances and altitude are visually appreciated by depth perception, either for "relative flight" or accurate landing.

c) Ground safety :

The local control personnel of the airfield must finally appreciate the respective position of taxiing aircraft or aircraft presenting in finals when the air traffic is dense.

These few examples give us an idea of the importance of depth perception in aviation and show us that visual information are essential, in spite of instrumental aids.

PERCEPTION OF DEPTH

- The factors involved in depth perception are numerous and intricated and therefore it is still more difficult to understand and to measure.

- There are intrinsic and extrinsic, monocular and binocular, optical physiological and psychosensory factors.

- Depth perception follows two processes :

. a peripheral process of INFORMATION related to the physiology of the eye ball,

. a central process of INTEGRATION related to the visual cortex activity.

- To be more explicit, we will consider here both the monocular and binocular factors of depth perception.

1 - Monocular factors

a) Accommodation :

The accommodative effort of the ciliary muscle causes centripetal proprioceptive influx proportional to the distance of the object fixed by the eye. The resulting appreciation of distance is insufficient and is interesting only for very close objects. Besides it varies with age and becomes slower after the age of fifty. In aviation, accommodation is significant only for the coordination eye-hand in simple motions in the cockpit.

b) Movement parallax :

When the eyes move with relaticn to the surrounding objects or vice-versa, it creates an apparent or real displacement of the fixed object in relation to the others depending on their position in the depth field. The nearest objects move more or faster than the fartherst, at a certain angular speed. The variation in the parallactic angle between the various objects gives us an idea about their distances. This information is interesting for any distance and any speed. In aviation it is significant for low altitude and high speed flight.

c) Apparent size of the retinal image :

It depends on the size of the object and on its distance from the eye. When the size of the object is known, it is possible to locate it in space if it is motionless and to know whether it comes nearer to the observer or moves away if it is mobile. The factor of depth perception, related to memory and experience, allows for comparisons but may cause illusions. It is involved in the appreciation of distances from 4 miles to infinity (KARLSBERG). Flying personnel use it for visual interceptions and air-air shooting.

d) Association with earth-bound elements :

It consists of three factors :

- Overlapping of contours

When an object is located between the eye and another object, it overlaps the other and hides it. It is located nearer. If it is transparent and lets the background be seen, depth perception is less distinct. In aviation, it is very important for approach or for landing on a rugged surface.

- Shadows :

In day-time when the weather is sunny, objects cast shadows on the background and the objects located behind them, thus accentuating their respective location. The sun rays also bring out the relief, shadowing the base of protruding objects and the top part of hollow objects. Low altitude flight is made easier by the resulting constrast.

- Linear perspective :

It is characterized by the convergence of right lines to infinity, a very important element of height appreciation when the aircraft is going to touch down.

e) Air perspective :

Distinctness, brightness and color of objects are conditionned by the transparency of the atmosphere. The furtherst objects are bluish and indistinct whereas the closest are distinct and contrasted. There is then a danger of illusion in low altitude flight ; a light haze causes an illusory decrease in the size of the obstacles and makes them appear more distant ; pure air makes the target seem closer than it is and magnifies its proportions (RUBIN).

- All these monocular factors lead to a deficient and very difficult depth perception. It proceeds by trial and by analogy and requires an effort. It seems sufficient in the every day life.

. A congenital monophtalmus or a young person exhibiting strabismus, progressively has a "notion" of depth perception which allows him to do some simple tasks.

. On the contrary, an adult who lost one eye in an accident is very awkward at the beginning (he pours down wine outside of his glass). Re-education is not easy. He must first forget the binocular concepts of depth by psychologically inhibiting his previous visual impressions before he can have new, indistinct and rarely spontaneous depth impressions.

- In aviation, we saw their deficiencies and their limits. They permit routine flights above known landscapes when the sky is clear and uncomplicated landings (LEWIS, KRIER). But they condition a certain slowness of depth perception and this psychosensory latency is detrimental to SAFETY (PERDRIEL).

2 - Binocular factors

They are significant for man because of his frontal eyes, of the corresponding points on his retina and his differentiated maculae, and also because of the hemidecussation of his chiasma and of the organization of his visual cortex.

a) Physiological diplopia :

It exists for any object in our field of vision. One must only pay attention to become aware of it. It is, in fact, impossible to see distinctly at the same time two objects aligned one behind the other. When one fixes the closer object, the other one is seen double and vice versa. Any simultaneous "focusing" is impossible. Thus, unconsciously, our brain registers a depth in the visual field by neutralizing the disturbing element, i.e. diplopia. This phenomenon is particularly frequent in near vision and disappears by closing one eye.

b) Convergence :

- The convergence effort of both eyes to fix a point is proportional to its distance, as it is for monocular accommodation. It causes the same proprioceptive depth sensation.

- In aviation, convergence is significant only for distances from 60 to 100 ft, and low or null speeds (landing, flight in formation, flight refuelling).

c) Stereoscopic perception :

The highest degree of binocular vision, a true "luxury" (PARINAUD) is the perfect depth perception.

- The location of the spatial points which produce an image falling on corresponding points of the retina in binocular fixation is a curved and grossly spherical surface (HOROPTER), the center of which is located between the two eyes.

- Because of the interpupillary distance, there is a slight disparity in retinal images. Owing to the CONVERGENCE -and divergence- eye movements, both images are combined into a single one. This fusion has a certain amplitude. It may origin from points located either slightly behind or slightly before the horopter without DIPLOPIA.

- The fusion of non identical retinal images given by each eye produces volume or depth perception in a psychological act of projection and mental analysis which eliminates diplopia.

- This sharply differentiated depth perception is precise, easy and instantaneous. It gives the best space perception but is limited to a distance of 4 miles (KARLSBERG).

- It is the only perception in aviation which permits depth vision in an unknown environment, critical maneuvers without resorting to habit (for instance, size of objects knowledge). Stereoscopic perception guarantees the pilot's safety.

MEASURE OF DEPTH PERCEPTION.

- It is necessary to measure depth perception everytime we want to analyse this performance in a subject or compare it with another subject's performance. This determination is essential in aviation because the subjects have to be classified according to their capability of accomplishing certain tasks.

- It is difficult to measure depth perception because of the multiplicity of the involved factors. Which is the most representative of the function ? Which should be taken into consideration ? Is it measurable ? In fact, some factors are qualitative (disparity of the retinal images, diplopia) and can be evaluated ; others are quantitative (accommodation, convergence) and are measurable.

- It is necessary to find a process for the evaluation of the global function of depth perception, considering on the one hand both physiological and optical aspects and on the other hand, the psychosensory aspects. This process should be easy to implement and rapid and the results significant. Finally, it should be adapted to the occupational efficiency of the pilot.

- In reality, we use two types of apparatus which involve both main components of depth perception. They are used for binocular tests, the results of which cannot be superposed and must be confronted to obtain a global evaluation of depth perception.

1 - Stereograms (optical and physiological component)

- They are based on the principle of the stereoscopic parallax. It is the sum of the angles of the eye rotation to fix one point and then a second and more distant point located on a different horopter. A simple calculation shows that the stereoscopic parallax is equal to the difference between the angles at the top of two isosceles, the common base of which is the interpupillary distance and the top one of the fixed points.

- From these theoretical data, stereograms are established, which are graduated according to a stereoscopic scale giving a depth sensation against the background. In other words, the observer must say if he sees a mark (figure, symbol) displaced in depth when compared to the principal plane. The examiner immediately obtains the value of the corresponding parallax and thereby measures stereoscopic acuity. The test reliability depends on the conditions, which must always be exactly the same : 120 lux illumination (BEYNE and MONNIER), motionless head, time of examination : 3 seconds.

a) Pulfrich's test :

The test is performed using a S.O.M. stereoscope. Binocular apparatus simultaneously permits fixing the examination distance and eliminating accommodation and convergence. It is probably the most precise test. However, the setting of the interpupillary distance and the nature of the stereogram make its performance sometimes difficult.

b) Wirt's test :

It requires a set of vectographic polaroids which are looked at through polarizing glasses. It is easy to use in the shortest time and gives two responses : existing stereoscopic vision -qualitative aspect- and value of the stereoscopic parallax -quantitative aspect-, but it lacks precision. As a matter of fact, the head moves ; besides a certain asymmetry of the plates already gives a clue about the responses in monocular vision.

- It is said that stereopsis is very good for a 20 sec. parallax, satisfying for a 30 to 35 sec. parallax and beyond that, stereoscopic acuity is insufficient or bad.

2 - Stereoptometers

(The psychosensory component).

- Stereoptometers are apparatus with vertical bars, mobile in depth which have to be put in alignment in a frontal plane using a wire (HOWARD-DOLMANN) or an electric motor (COLAJANNI). The test is performed at a distance of 5 meters ($\simeq$ 16 ft) in 3 seconds. The average displacement of the bars in depth must not exceed 30 mm (1.18 in.) after 5 trials a 10 mm (0.39 in.) displacement corresponds to a 5 sec stereoscopic parallax).

- This method, which is simple and closer to the everyday life conditions, explores the practical depth vision and gives a good idea about the subject's occupational capacity. However, it involves the movement parallax and the size of the cylinder, which are the monocular factors of depth perception.

- These two groups of tests are finally complementary :

. the stereoscopic parallax is a physical criterion related to the eye's optical characteristic to separate 2 points located one in front of the other. It is due to the quality of the binocular visual information, especially of the corresponding retinal macula.

. in reality, the real evaluation of depth comes from the mental interpretation of different optical data obeying psychosensory criteria (BEYNE and MONNIER).

It is due to the visual information from the retinal extra foveolar zones.

- This explains that 50 % of the subjects have a very good stereoscopic perception, 40 % an average stereoscopic perception and 10 % none at all.

FACTORS DISTURBING DEPTH VISION.

1 - Extrinsic factors

a) Ground configuration at low altitude :

- due to the lack of a visible horizon,
- due to the lack of marks against a uniform background (water, sand, snow),
- overflight of a crest causes a tendency to nose up when the aircraft flies nearer, to nose down when the aircraft flies away,
- approach causes on overestimation of height if the runway slopes up, an underestimation if the runway slopes down.

b) Speed :

Hovering, low speed or very high speed flight are as many determining factors of depth evaluation.

c) Light environment :

- In fog, the distance and size of objects are not correctly evaluated.

- In the night, night myopia or autokinetic illusion are important factors of error,

disturbing spatial orientation because of the resulting misevaluation of distances and movement. In fact, when it is observed during the night, a motionless illumination point seems animated with slight oscillations or slow displacement as soon as the 9 th second is reached (CARR, SKOLNIK).

2 - Intrinsic factors

a) Ocular :

- Ametropia reduces depth perception (MAC CULLOCH, CRUSH), especially myopia. Aphakia and retinal lesions of the macula produce the same effect.

- Accommodation disorders also have a negative effect on depth perception.

b) Sensomotor :

For instance, convergence deficiencies, heterophoniae and oculomotor disorders.

- Hypoxia decompensates major heterophoniae. It causes a temporary disorder of the evaluation of distances and height which is a nuisance to the pilot about to land because of an under-evaluation of height (RICKENBAUER, TOULANT).

- Stereospic perception is little changed by hypoxia. For HEINKE, changes occur a short time before anoxemic loss of consciousness. A temporary rise in the stereoscopic parallax ground 4,000 meters ($\simeq$ 13,123 ft) has been noted by DUGLIET, physiological threshold of adaptation to altitude. He ascribes it to a "psychic paresis".

c) Central :

- Depth perception disorders are caused by flight induced fatigue, air sickness, noise (GROGNOT, PERDRIEL, LEBLANC), stroboscopic effect of helicopter rotors (GASTAUD).

- They are also caused by lesions in the occipital visual cortex, because of a disturbance in the space-body relationship.

- GERHARD has finally shown that there was a correlation between stereoscopic perception and the intelligence quotient, a statement which is in agreement with the ambiguity of interpretation of certain optical illusions relating to depth representation.

CONCLUSIONS.

- In spite of considerable progress made in aviation in the field of navigation aids, no instrument can replace the eye for certain maneuvers or certain critical flight phases.

- Depth perception is one aspect of visual performance which makes it an essential attribute for the pilot for completing his MISSION and for his SAFETY.

- Depth perception is practically not influenced by aeronautic conditions, however, it is a fragile and labile perception in its ophthalmological factors.

- That is the reason why strict norms have to be respected and a thorough functional and anatomical examination of the visual apparatus has to be performed for the SELECTION. CHECK-UP needs not be so strict, for we know that the psychosensory abilities of depth perception can be improved by habit and education, i.e. training.

- In case of temporary deficiency, rehabilitation is possible once the depth perception disturbing factors have been suppressed or corrected through orthoptic techniques.

VISUAL PROBLEMS RAISED BY LOW ALTITUDE HIGH SPEED FLIGHT

by

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GENERAL DESCRIPTION.

1. Flight definition

This flight is called low altitude supersonic speed (LASS) flight by the Anglo-Saxons.

The aircraft flies at altitudes ranging between 100 and 800 feet ($\simeq$30-250 m) and speeds ranging between 450 and 600 knots (830-1100 km/h), i.e. transsonic and supersonic speeds.

2. Missions at low altitude and supersonic speed

Whether they are training missions during peace time or wartime operations these missions vary according to the topography of the overflown area and the weather conditions. They both have a surprise effect.

Actually, hedge hopping permits escaping radar and antiaircraft defense detection systems as well as interception maneuvers.

VFR reconnaissance or photographic missions and bombing missions raise numerous visual problems. Vision gives 90 % of the information in this type of flight.

The search for a target requires :

. under *VFR conditions* : VFR navigation based upon detection and identification of characteristic and rough landmarks.

. under VFR and IFR conditions : map reading as well as radar and instrument panel observation.

3. *Means of study*

- First of all, the observations of the flying personnel as soon as supersonic speed is reached (FRAZER, SERIS, AUFFRET).

- Mass surveys for flying personnel (MERCIER, PERDRIEL, GANAS).

- Experimentation (SOLIDAY), "LASS" flight simulators (SADOFF, WEMPE in NASA), vibration platforms (LAMAS of the CEV in Bretigny)*

4. Effects of flight on vision

By its operational characteristics the LASS flight leads to physical, physiological and psychological stresses which affect vision by modifying the visual information and the visual performance and by disturbing the visual function.

CONDITIONS MODIFYING VISUAL INFORMATION

1. Transparent surfaces

. Air trickle flow :

At transsonic speeds (0.85-1.2 Mach) compression and turbulence of air trickles on the windshield cause a shock wave. The air loses its homogeneity and causes a deviation of the light rays by discontinuity of its refraction index (e.g. the mirage phenomenon). This phenomenon causes visual aberrations and an apparent displacement of objects (WALCHNER, RAMHAUSKI).

* LAMAS = Laboratoire de Médecine Aérospatiale
(Laboratory for Aviation and Space Medicine)

* CEV = Centre d'Essais en Vol (Flight Test Center)

. Squashing insects :

In the warm season, at the end of the day, the aircraft may pass through real clouds of insects when flying close to the ground. These are squashed on the windshield which becomes opaque and less transparent.

. Collisions with birds :

Collisions with birds occur frequently at altitudes below 300 m. They can cause serious eye damage considering the violence of the impact.

At high speed, protection is impossible both for hunter and game !

2. Kinetic heating

At low altitude and high speed the aircraft crosses the densest atmospheric layers. Friction with air molecules heats the surface of the aircraft. The temperature inside the cabin starts rising as soon as a speed of 0.85 Mach is reached.

If the air-conditionning is insufficient or fails, the pilot's perspiration can steam up his helmet and glasses. Drops of sweat can even irritate his eyes and affect his vision.

3. Exterior visibility

. Contrast on ground :

The ground flashes by under the aircraft wings as a mosaic of fields, meadows and forests which make up an heterogenous background. The searched target is concealed : another aircraft flying at the same altitude is not detected since it does not detach itself from the background, due to the lack of contrast. It is altogether different at higher altitudes where the aircraft contrasts against the sky.

. Haze :

Near the ground, the air contains a lot of water vapour which forms haze clouds in the early hours of the day. The aircraft which flies through these clouds is suddenly immersed in an opaque environment with a lower luminance level.

On the contrary, when the weather is clear, the sun rays diffract and cause discomfort glare.

. Night flight :

Night flight has certain advantages for LASS missions : few atmospheric turbulences ; the aircraft is less easily detected ; no visual discomfort perpetuated by the flashing by of the landscape under the pilot's eyes.

On the other hand, navigation and target detection are difficult. It is also difficult to assess the altitude.

All light sources become very visible. The pilot is unconsciously attracted by city lights and deviates from his route. Lights, searchlights and flares cause dangerous visual disadaptation.

. Glare :

Besides the above mentioned sources of glare during night flight, we should consider the reverberation of the sun on the smooth surfaces (sand, snow, water) and the sun rays emerging out of the horizon (disability glare).

All these conditions affect the precision and efficiency of vision.

CONDITIONS AFFECTING VISUAL PERFORMANCE

1. Speed

Speed introduces a 4th dimension in the LASS flight : TIME.

. Spatial scotoma :

The visual act is not instantaneous : it follows a certain chronological pattern (GOODSON, MILLER) revealed by electrophysiological techniques (ERG, VEP, EMG).

- The detection of visual information requires some time : latency of the retinal coding process + time for the conduction in the optical pathway + latency of the central decoding process. It is called the time of retinal-cortical perception (STRUGHOLD). Depending on the more or less favorable conditions, it ranges between 110 and 400 milli-seconds and

represents a time of apperception, a real spatial scotoma. Vision is totally ineffective while the aircraft covers a certain distance. We can say that the pilot is late in detecting the given information.

- The identification of visual information involves several reflexes, fixation, fusion, accommodation and pursuit before the motor decision is made. This new time lag which adds itself to the apperception time is the time of voluntary motor response which is approximately 0.65-1.5 second.

In other words, at Mach 2 the pilot needs 2 seconds to react to a visual stimulus located at the center of his visual field, 3 seconds if the stimulus is more towards the periphery (FICHTBAUER). At Mach 1, there must be a distance of 2 km between the aircraft and an obstacle in order that the pilot can avoid it (PERDRIEL).

- From these observations emerges an unusual but very important concept : the concept of VISUAL VELOCITY which should be taken into consideration for LASS flights.

. Angular speed of visual scanning :

At low altitude and high speed, the objects on the ground seem to flash by very quickly under the aircraft. It soon becomes impossible to fix them as their speed exceeds the capacities of optokinetic nystagmus. This phenomenon involves another concept, that of DYNAMIC VISUAL ACUITY (LUDVIGH, MILLER). The acuity remains efficient up to a visual scanning angular speed of 10°/sec, which corresponds to the exploration by the eye of a 500 m-side square overflown at an altitude of 500 m and at a speed of 300 km/h, i.e. during 6 seconds (WUTHICH).

As previously, the exposure time of the target remains a fundamental datum for the visual act. For a visual scanning angular speed of 110°/sec, which is common in LASS flights, the visual acuity changes from 20/235 to 20/40 when the exposure time increases from 200 to 820 milliseconds (MILLER). In this case also the pilot must see quickly.

. Reduced visual field :

At high speed, vision becomes imprecise and blurred at the periphery of the visual field. We can say that its useful range is reduced or, in other words that the angle of useful vision is reduced.

In the same time, the threshold of voluntary motor response "moves away" from the eye.

Thus, at high speed, only the visual information coming from an area defined by the limit of efficient vision and the threshold of volontary motor response can potentially generate an effective response (WHITESIDE).

We can conclude that speed accounts for lost time in the recognition and identification -sometimes erroneous- of a target while reducing the efficient visual field. It increases the risk of collision.

2. Acceleration

. Turbulence :

Turbulence depends on the overflown terrain, weather conditions, type of aircraft and wing shape.

It generates aperiodical jerks of variable frequency and amplitude at 0.1-0.4 G. (BUFFETING, TABASSAGE).

The effects of turbulence are mostly felt in the head which is more mobile than other parts of the body. If they last more than 90 minutes, they induce discomfort while the pilot is reading maps and watching the instrument panel.

. Aircraft maneuvers :

In a terrain following flight configuration the search for a target and the feints to avoid interception require very tight maneuvers such as turns and obstacle jumps. The pilot is exposed to positive vertical accelerations (Gz +) which can lead to various visual disorders :

- oculogravic illusion, i.e. apparent displacement of objects in the sense opposite to acceleration,

- eye-hand incoordination,

- disorientation, Coriolis pseudovertigo,

- at about 4 G, visual blurring (grey veil) ; above 4 G narrowing of the nasal visual field which precedes blindness (black veil) and foretells loss of consciousness which occurs between 5.5 and 7 G.

The blood mass is literally centrifugated towards the lower limbs and the abdomen and leaves the carotid vascular region. The examination of the fundus under these condi-

tions shows a granulous blood flow, maybe even a vascular collapsus (DUANE).

3. Vibrations

Under the effect of aerodynamic vibrations or engine vibrations the viscera become resonant, especially in the upper half of the body.

Vibrations between 2.5 and 4 cycles/sec especially affect the eye ball (COERMANN).

Such vibrations disturb the physiological micronystagmus and apply on the eye ball periodical movements which disturb the vision and could create a distortion between the exterior visual information and the data displayed on the instrument panel.

All these conditions affect the physiology of the visual act. They are the cause of DISABILITY.

CONDITIONS DISTURBING VISUAL FUNCTION.

1. Noise

Noise causes central disorders which in turn lead to a state of weariness and general fatigue.

A drop in the humeral and ophthalmic arterial pressure has been experimentally demonstrated under the effect of noise.

PERDRIEL, GROGNOT and LEBLANC have shown that long exposure to dysharmonious and disagreable noises (98-100 dB at 50-5,000Hz) caused a decrease in the speed of colour recognition and an increase in the light threshold.

The high sound level in the cockpit of an aircraft in a LASS flight is therefore the cause of functional visual disturbances.

2. Workload

Hedge hopping leaves the pilot with a narrow margin of safety to avoid collision with the terrain or unforeseen obstacles.

High speed flight at such low altitudes makes VFR navigation and target detection difficult while the pilot is simultaneously reading the panel instrument and the maps. They become impossible at a speed of 600 knots.

The pilot must therefore constantly look outside and then inside the cockpit, using both his accommodation to change from far vision to near vision and his adaptation, which is submitted to the variations in the light environment changing from the outside to the inside.

This explains why the critical, maybe even dangerous LASS flight requires a very high level of concentration and sustained attention from the pilot. This constant tension leads to a state of fatigue, especially if it lasts a long time. In addition, the pilot is literally fascinated by his central visual field, which decreases his level of alertness in his peripheral visual field. At the same time, the evaluation of heights is gradually distorted. The pilot has an instinctive tendancy to pick-up altitude during the mission, especially if he came down rapidly to hedge hopping.

3. Psychological stress

The concept of danger, sustained visual performance at the limit of its capacities and sustained attention generate an emotional overload, especially during wartime, which can put the pilot in a certain state of mental excitement.

On the contrary, the overwhelming workload, fatigue and airsickness can cause a certain mental viscosity.

In both cases, the pilot's intellectual activity is reduced, just as much for detection as for interpretation and memorization of visual information.

All these conditions adversely affect the pilot's behavior at the highest level of visual integration.

MEANS OF ACTION AND PREVENTION.

These means are designed to ensure an optimal MAN-MACHINE interaction, best filling the MISSION requirements while abiding to the SAFETY RULES.

1. Selection

Selection permits establishing the PROFESSIONAL CAPACITY of the flying personnel by

testing the various aspects of their visual function.

. The visual acuity must be particulary high : an acuity of 22/25 without correction is required for each eye at the admission visit. Pilots wearing corrective glasses are not allowed to fly LASS missions. Subjects exhibiting hyperopias exceeding 1 dioptry are eliminated so that correct accommodation is ensured.

The visual efficiency should be tested by "on the spot" examinations so as to take into consideration the VISUAL VELOCITY and the DYNAMIC VISUAL ACUITY.

. The visual field must be normal, both in its peripheral limits and at the center. Any abnormality in the visual field is the cause of elimination at the admission visit.

. Normal color perception must permit identification of "aviation" safety colored lights presented at a distance of 5 m at an angle of 2 minutes during 1/25 second (BEYNE). We know how important it is that the pilot interprets rapidly the colored light signals in LASS flight.

. The sense of light must be tested, in a manner duplicating as closely as possible nightime conditions. The threshold of shape perception at night is established to be 0.12 candle/hm^2 (BEYNE). Resistance to glare must be normal for the subject's age.

. Normal depth perception requires a good oculomotor equilibrium and a normal binocular vision. In order that depth perception remains as efficient and rapid, subjects exhibiting esophorias above 10 dioptries, exophorias above 5 dioptries and hyperphorias above 1 dioptry must be eliminated. The stereoscopic ability is assessed using HOWARD -DOLMANN' s and COLAJANNI's instruments. The means of errors must not exceed 30 mm for 5 tests of 3 seconds each.

. The anatomical examination of the eye ball must show the eye ball is free of all abnormality or affection which could potentially impair its function.

2. Check-ups

The subjects undergo a yearly medical check-up to make sure that there are no changes in the visual performance which could affect flying SAFETY in LASS flights.

3. Training

Training is indispensable to maintain or improve the individual factors.

The pilot can be trained in flight or on a flight simulator and thus learn to watch, see quickly, interpret rapidly and, above all, sort out and memorize the visual information.

The LASS mission must be carefully prepared in order to point out the major landmarks or obstacles which will be encountered during low altitude navigation. Special maps, maybe even mock-ups will be used for this purpose. Finally, the pilot will be advised so that he learns to look way in front of him and that he reaches his flight altitude very progressively.

This whole preparation is designed to make the pilot CONFIDENT that if an unforeseen difficulty arises the mission can be cancelled.

4. Protection

For this type of mission causing the adverse effects we described, the protection equipement will necessarily include : anti-G ventilated suit and eye protection against glare.

5. Human engineering

This is an important chapter of ophthalmological ergonomics where the qualified doctor must collaborate with the engineers in the choice, development and control of the equipment and instruments.

. Canopy :

Well shaped, with transparent surfaces, maybe even cleaning possibilities during flight.

. Seat :

Height and position of the pilot inside the cabin ; shock absorbing seat.

. Instrument panel :

Lighting and display of data on the various display devices.

Information must be clear and not ambiguous. The most important information will be clearly displayed at the center of the visual field. Several systems are proposed, among which some are still being studied.

- head-up display where the most important parameters are projected onto the windshield,
- integrated systems where this information is concentrated on a central console.
- TV - type screens displaying permanently or on demand the most characteristic indications.

These systems give an anticipated picture of the future development of automatic systems :

- automatic interpretation of flight data by computer.
- automatic flight controlled by radar or laser systems.

CONCLUSIONS.

The combined effects of low altitude and high speed affect the visual information because of the time factor involved. This information, which is critical in LASS flight is always delayed compared to reality.

This delay cannot be reduced by the visual system whose physiology abides to immutable spatial-temporal rules.

It is therefore necessary to establish strict selection criteria with tests even more specifically directed towards the desired objective.

The means to explore the visual velocity and dynamic acuity must still be devised and applied on a practical basis.

Training keeps all its value if it can be advised that each pilot flies only unfrequent or staggered flights and a double crew is used. Progress must still be made in simulators used for training young pilots.

The visual aids for flight and navigation will provide a solution allowing anticipation of the information and FORESIGHT in order to compensate for the time lag induced by aircraft speed.

THE CONTRIBUTION OF ELECTROPHYSIOLOGY IN THE SELECTION AND OPHTHALMOLOGICAL SURVEILLANCE OF FLYING PERSONNEL

by

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I. INTRODUCTION

1/ The major role of visual information in aviation is not questioned. We know that this information requires various levels of adaptation. To make sure that the subject has adequate adaptation levels, a series of functional examinations must be performed. This checking operation must be carried out at the admission visits in order to detect potential abnormalities and to evaluate their possible evolution.

2/ During the pilot's career, it is possible that the quality of visual information changes. Such changes may be due to :

- Physiological phenomena related to the aging process (reduced visual acuity, accomodation and chromatic perception),
- Pathological sequelae after medical or surgical eye affections,
- Ocular complications resulting from general pathology (hypertension, diabetes...),
- Iatrogenic diseases secondary to general therapy (anti-malaria drugs, ovulation inhibitors...).

3/ Most examinations are based on subjective methods which are questionable as they often vary in time and only provide experts with documents of questionable value. These documents can indeed be questioned and disproved by the examined person.

This is why it is sometimes necessary to rely on objective and perfectly codified examinations which thus become unquestionable. Among such examinations, electrophysiology certainly has a special value.

2. WHAT IS VISUAL ELECTROPHYSIOLOGY ?

The visual sensation is only the expression of a visual message generated on the retina and transmitted by the optical pathway to the occipital areas where it is decoded.

To each one of these phases (reception, transmission, decoding) correspond electrophysiological phenomena which, for a long time, remained experimental before being used for clinical purposes.

The necessity to collect and store these bioelectrical potentials can be explained by the limits of ophthalmoscopic and functional explorations designed to establish the diagnosis. It is also difficult to define precisely the exact magnitude of the disorder.

Electroretinography (ERG), electrooculography (EOG) and the study of the visual evoked responses (VER) have become simple examinations, owing to the technical advances in the field of stimulation, computation and recording. These examinations often give useful information influencing the diagnosis and help to foretell retinal affections as well as disorders in the optic tract.

In order to understand electrophysiology one must remember that the retina is composed of several layers, i.e. from the outside to the inside :

- pigmented epithelium,
- photoreceptors,
- bipolar cells,
- ganglionic cells.

There are two types of photoreceptors : cones (visual acuity, chromatic vision) and rods (night vision). They are not homogeneously distributed : cones are predominant in the central area of the retina, whereas rods are more numerous at the periphery.

The cylindraxes of the ganglionic cells go, by means of the optical pathway towards the occipital cortex.

It should be noted that the fibers of the temporal retina tend towards the homolateral cortex whereas the nasal fibers tend towards the opposed cortex, after crossing the median line in the chiasma. The macular fibers are both direct and crossed.

The occipital visual areas occupy a significant volume, inside which the macula has a preferential place. Thus, the smallest retinal surface occupies the most important cortical area.

This anatomical review shows, from an electrophysiological standpoint, that :

- the various retinal layers can be investigated ;
- it is possible to dissociate the responses given by the photopic and scotopic systems ;
- the permeability of the visual pathway can be tested ;
- it is finally possible, considering the anatomical characteristics, to try and localize retinal lesions.

1/ Electroretinogram (ERG)

BREGEAT defines the electroretinogram as the "recording of an electrical response by the retina to a strong light stimulation". It is thus defined as a *retinal action* potential following light induced biochemical phenomena. It is a total response, initiated by the photoreceptors and especially by the interface visual cells/bipolar cells.

Using technical stratagems, a potential is picked-up on the cornea, which is then amplified and recorded. It is possible to study either single responses, following stimulation, or cumulative responses, i.e. a mean response.

It is thus possible to study a negative wave (wave "a") and a positive complex in which a "b1" and a "b2" wave can be differentiated. The "b1" wave corresponds to the activity of the photopic photoreceptors (cones). The "b2" wave corresponds to the activity of the scotopic photoreceptors (rods). Its amplitude increases during adaptation to darkness.

The ascending part of "b1" reveals oscillatory potentials or "e" waves (e1,e2,e3) whose significance is more difficult to establish.

The ERG can thus be studied for its morphology, amplitudes and latency times separating the times of culmination from the times of stimulation.

2/ Electrooculogram accepted as retinal examination shows the rest potential existing between the retina and the cornea. As it is impossible -for clinical purposes- to fix an electrode on the posterior pole of the eye ball, one studies the variations in potential generated in the periorbital areas when the eye ball moves along its horizontal axis.

The examination includes two phases :

- a phase while the retina is adapted to light and
- a phase while the retina is adapted to darkness.

The curves exhibit a series of alternatively negative and positive deflections, corresponding to the lateral position of the eye ball, and follow the basic line when the eye is in its primary position (straight ahead look).

The amplitude of the responses is measured in microvolts. These measurements permit us to study the basic value (Vb) and the ratio photopic activity/scotopic activity (ARDEN's ratio). From a practical standpoint, these two values account for the EOG activity.

The EOG depicts the activity of the pigmented epithelium and of the most external part of the photoreceptors.

These two examinations thus permit testing an important position of the retinal activity, more specifically the site where the sensory message is generated.

3/ The visual evoked response recorded by electrodes placed on the occipital cortex indicates the arrival of the sensory message. By its morphology, amplitudes and latency times it reflects the permeability of the visual pathway and its cortical integration.

The recording process requires the use of a computer which only keeps the visual response following light stimulation in its memory. The random responses which make up the electroencephalogram are not taken into account. This permits obtaining better structured answers, not influenced by artefacts.

The eyes can be simultaneously or individually stimulated, using different wave lengths. It is thus possible to test in priority cones or rods since different fibers are tested according to their topography in the visual pathways.

The evoked potentials are composed of several waves (positive and negative) with different amplitudes and latency times following the time of stimulation. The significance of the various waves is still unclear. We shall note that the first waves indicate the primary potentials of integration on area 17 of BRODMANN. The following waves, of small amplitude, might reflect potentials of association with areas 18 and 19.

With these three examinations, it is thus possible to test the retina, to check the permeability of the visual pathway and the arrival of the sensory message.

These examinations are commonly used in an Examination Center for Flying Personnel.

3. WHAT CAN BE EXPECTED FROM ELECTROPHYSIOLOGY.

1/ For diagnosis

In most cases, the functional exploration of the visual act which completes the clinical examination permits the doctor to confirm the subject's fitness or to establish a diagnosis defining him as unfit. However, there are limit cases where the symptomatology is essentially subjective and where the responses to the functional exploration show minor or no disorders.

The use of the three means of exploration permits the specialist to locate a deep lesion. Such a diagnosis is often very difficult to establish if only ophthalmoscopy is used, even if it is associated with biomicroscopic examination of the fundus.

Electrophysiology sometimes brings an interesting element to confirm or disprove a diagnosis, e.g. the discovery of unilateral atypical retinal pigmentations raises the hypothesis of pigmentary retinitis. This can only be verified by electrophysiology.

Finally, these examinations are easy to carry out and can be renewed without risk. It is then possible to follow the evolution of an affection.

2/ For prognosis

Repeated examinations make it possible not only to follow the evolution of an affection but also to make a prognosis. This prognosis is taken into consideration by the medical expert when deciding how long the subject will remain fit, how often he will have to come for check-up visits or how long the temporary unfitness will last. He will give a favorable or unfavorable opinion when requesting a possible derogation to the standards.

Certain subjects are prescribed a prophylactic treatment and must be checked with electrophysiological examinations. They may be taking a prophylactic drug treatment -antimalaria drugs for example- having a known adverse action on the retina. The same will be true for diabetic subjects who are authorized to fly.

Prophylaxis can also be surgical : the discovery of peripheral retinal lesions can lead the medical authority to prescribe preventive therapy using LASER photo-coagulation or cryo-coagulation. In both cases the subject must be kept under medical surveillance.

Finally, in certain cases, subjects may continue their flying activities after ocular surgery such as extraction of the lens, surgical normalization of an ocular tonus, surgery in case of retinal detachment, photo-coagulation of a recurring central serous chorio-retinopathy.

Medical surveillance is also necessary in all these cases.

When used for diagnosis or prognosis, the results of electrophysiology should never be dissociated from those of the clinical and functional examinations, but rather always be compared to them.

In case of an isolated bioelectrical disorder, it will be necessary to repeat the examinations before making a decision.

4. ELECTROPHYSIOLOGY AND SELECTION.

1/ As a function of functional changes :

. It is usually easy to diagnose hereditary or acquired dyschromatopsias using ISHIHARA's tests, the chromoptometric lantern, the anomaloscope and tests of FARNSWORTH. However, in some cases, the dyschromatous subject may deny his abnormality ; in other cases, the medical expert tries to integrate this disease into a nosological framework. He can then perform these examinations. We know, for example, that the amplitude of the "b" wave is reduced in protanopic subjects who do not perceive red (J. FRANCOIS). We can notice, in the same manner, a diminution in the "b2" amplitude for subjects exhibiting an abnormality when exposed to a green light (P. ROBION, G. PERDRIEL). Some authors found that changes in oscillatory potentials (e waves) are associated with abnormalities of color vision which we personnally do not consider significant at all.

The EOG brings no information on the abnormalities of color vision. In spite of SEGAL's theory which describes the pigmented epithelium as a selective receptor of red, it does seem that color vision is thoroughly independant from this retinal layer.

Currently, the VER cannot be used in this study.

Finally, the study of the ERP (early receptor potential) which is still difficult to record seems, however, of great interest.

. Abnormal vision at low luminance levels can be succesfully explored using electrophysiological examination, especially electroretinography and electro-oculography.

Already in 1963, at the VI th International Congress of Aviation Medicine in Rome, G. PERDRIEL had drawn the attention on the value of ERG.

In 1965, at the fall AGARD Meeting in Munich, MERCIER and PERDRIEL and myself discussed this subject. Recently, I discussed again with MANENT about the value of ERG as a means of discovery of abnormalities in flying personnel.

When a pilot confesses being affected with nyctalopia or when this condition is suspected during adaptometric or scotoptometric examinations showing nearly normal results (with nearly normal thresholds), the ERG study can prove a disorder in the "b2" wave during the process of adaptation to darkness. The EOG will display an abnormal amplitude for the adapted retinal value, hence an abnormal ratio.

In all the marginal cases, the study of the change in amplitude of the "b2" wave during adaptation to darkness and in the photopic/scotopic ratio of the EOG make it possible to assess the exact value of vision at low luminance levels.

Finally, the observation of a particular recording permits the doctor to diagnose OGUCHI's disease which will be confirmed by ophthalmoscopic examinations after adaptation to light.

Insufficient photostress recovery test often coincides with an ophthalmoscopic change. However, the fundus may sometimes be normal.

Retinal electrophysiology shows whether the retinal function is normal or abnormal.

The demonstration of an abnormal "b1" wave or of an abnormal EOG basic value explains the functional abnormality and permits establishing a prognosis.

2/ As a function of ophthalmoscopic changes :

Certain central or peripheral ophthalmoscopic lesions often lead to few functionnal changes as they are identified at the very beginning of their evolution.

With electrophysiological examinations it is possible to differentiate between degenerative evolutive lesions and non evolutive scar lesions.

For papilla displaying normal aspects (false oedema) a thorough investigation must be performed before a decision can be made. The VEP has a special role in this exploration as it can be compared to its symmetrical V E R.

5. ELECTROPHYSIOLOGY AND MEDICAL SURVEILLANCE.

1/ Types of pathological aggressions:

Between two medical examinations the pilot may develop an eye disease and its sequelae can be observed. All the examinations must be performed in order to decide whether the pilot can pursue his carreer or not. Some aspects of macular chorio-retinitis seem to be well limited. Only the ERG and EOG examinations can show a more diffuse retinal affection which will then modify the prognosis.

Abnormalities related to high blood pressure, arteriosclerosis or diabetes will be regularly checked with electrophysiological examinations.

ERG has an interesting prognosis value, especially for diabetes.

Photopic changes and the disappearance of the oscillatory potentials can precede more serious ophthalmoscopic and functional disorders and lead to a bad prognosis.

On the contrary, conservation of a normal ERG is a favorable sign of the evolution of diabetes.

Trauma induced disorders will potentially lead to bioelectrical modifications, but these will remain unchanged after stabilization.

A particular situation may also arise when pilots who have lost their motivation for flying activities wish to be declared unfit by describing a series of visual symptoms. It is difficult to interpret the functional examinations as the answers are more or less anarchic. Normal visual electrophysiology permits eliminating any anatomical substratum. These techniques often made it possible to deny alledged disorders of night vision.

2/ Action taken :

It is necessary to give a complete check-up after a pilot has undergone surgery.

In the case where a retinal detachment has been successfully treated by surgery with conservation of the visual functions, the ERG, EOG and VER are useful data. They confirm or deny stabilization and can provide useful information on the bioelectrical activity of the other eye.

The use of laser as a prophylactic or therapeutic agent, either on the central retina or on the peripheral retina leads to transient electrophysiological alterations. If such alterations need not be taken into consideration fo- subjects with no safety responsabilities, they certainly must be for flying personnel. They can resume flying only after normalization or stabilization of these examination results.

3/ Following effects of long-term treatment :

The retinal toxicity of synthetic anti-malaria drugs requires medical surveillance of personnel exposed to such hazards, either for prophylactic or for therapeutic purposes (dermatology and rhumatology).

This surveillance is both functional and electrophysiological (ERG and EOG). The early signs of poisoning are revealed by these examinations while the color vision and the visual acuity are not yet affected. It is then possible to stop the treatment at a stage when the lesions can still be reversed.

Patients at the end of an ethambutol treatment may be authorized to resume flying. Functional and electrophysiological follow-up examinations will be particularly stringent.

4/ Contribution to the search for useful therapeutic effects :

Electrophysiological examinations permit the doctor to judge objectively the action of the prescribed therapy.

These methods are also used to find pharmacodynamic substances capable of improving the visual performance.

Finally, the adverse influence of certain physical or chemical aeronautical factors on the visual function could be tested using these methods.

6. CONCLUSIONS.

In this expose we believe we have shown you the value of visual electrophysiological examinations for the selection and medical surveillance of flying personnel.

These examinations are all the more important as they are objective and provide information which can be kept as a document. They have a diagnostic and pronostic value since they can easily be repeated.

However, we should remember that these examinations should not be interpreted without taking into consideration clinical data and that these results can, but very rarely, be used without being compared to clinical and functional results.

The techniques described in these pages are now commonly used for the ophthalmological examinations of flying personnel, both military and civilian.

"AUDITORY INFORMATION OF FLYING PERSONNEL"

(Anatomical and Physiological Basis)

by

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Auditory information for the aviator is the same, of course, as that of other people. Anatomical integrity of the auditory nervous paths is necessary. However, correct auditory information is possible for aviators presenting certain types of lesions in the sound transmission system (middle ear). This is possible only because the information is transmitted by radiophony (VHF, UHF) and allows him to raise the sound volume if necessary.

1. ANATOMIC REVIEW OF THE AUDITORY SYSTEM.

A/ Ear

It consists of a series of cavities in the Petrous-bone (temporal bone) and is divided into 3 parts :

- . outer ear
- . middle ear
- . inner ear

a) Outer ear :

with : the auricle
the external auditory canal.

The auricle is a fibrocartilaginous, pleated surface which is an acoustic ear-trumpet and directs the sound waves to the external auditory canal. Its role is not very important in man but it is in certain animals, for which the mobile and swivelling auricle is a very sensitive organ of hearing search and detection.

One must know that the peripheral coiled margin of the ear is called the HELIX ; its central cavity towards the duct is the CONCHA, with the anterior small cartilaginous projection of the TRAGUS.

The external auditory canal, which is 8 mm in diameter and is 25 mm long is made up of a cartilaginous part and an osseous part. It is angled and therefore, in otoscopy, it is necessary to pull the auricle up and backwards to see the eardrum which closes it medially.

b) Middle ear :

It is deep to the outer ear and is a cavity full of air : the TYMPANIC CAVITY.

The ear-drum separates it from the external auditory canal. The inner ear opens into the deep wall of the tympanic cavity by the round window and the oval window.

The tympanic membrane is an elastic, thin but solid membrane, roughly circular, of about 1 cm of diameter and with a 45° slope against the horizontal plane. It is fitted into the tympanic sulcus by the of Guerlach's ligament The larger part of it forms the Pars Tensa, in front of the aditus and is the inferior part of the tympanic cavity ; the superior part constitutes Shrapnell's membrane (above the anterior and posterior ligaments of the malleus) which is lateral to the attic. The first ossicle is the malleus, the handle or long process of which fits between the mucous and the cutaneous layer of the Pars Tensa. Its lateral process protrudes and is the main tympanic mark in otoscopy. Its neck supports a huge head which articulates with the incus. The short process of the incus lies in the aditus ad antrum and the very thin long process goes down to the stapes with which it is articulated by the tiny lenticular bone.

The stapes is composed of a head, a neck and 2 crura and articulates with the oval window by its base and the periplatellar annular ligament.

The ossicular chain, which is thinly articulated and thus very mobile, is supported by ligaments, the most important of which is the malleus suspensory ligament and subtented by the tensor tympani muscle anteriorly and the stapedius muscle posteriorly.

The mucous membrane of the tympanic cavity envelops these elements, thus forming mesenteries.

The main mesenteries, the plica stapedis and the medial and lateral incudal folds

separate the attic from the mesotympanum reducing communication between these two areas of the tympanic cavity to two narrow apertures, the isthmus tympani anticus and posticus.

Finally, the osseous Eustachian tube, which is extended to the pharynx by the membranous tube, opens into the lower anterior wall of the tympanic cavity. It allows entry of air into the tympanic cavity which is necessary for the normal physiology of the sound transmission.

The posterior tympanic cavity communicates with the mastoid antrum by the aditus and certain periantral cells.

c) Inner ear :

It has long confused the anatomists so they called it the labyrinth. In fact, its structure only seems complicated : there is a rigid box, the bony labyrinth, which contains the membranous labyrinth.

Let us first describe the membranous labyrinth, which is quite simple : it is composed of two small central membranous spheres, a posterior one, the utricle and an anterior one, the saccule, connected by a membranous duct, the endolymphatic duct (which is terminated by the endolymphatic sac).

We will review the utricle later when we study the vestibular system, for the semicircular canals terminate into it and they both constitue the posterior labyrinth containing the sensory organ of equilibration.

The saccule is an intermediary part between equilibration and audition. Its physiological part in man is not clearly understood.

The anterior labyrinth or cochlear duct or cochlea terminates into it (by the canalis reuniens) and makes two and a half spirals.

Its section is triangular :

It is thus formed of 3 walls and contains a fluid, the endolymph (which is also found in all cavities of the membranous labyrinth).

The basilar wall of the cochlear duct is the thickest for it contains the auditory receptive sensory organ, called the organ of Corti, which we will review in detail later.

The cochlea or cochlear duct is located in the osseous cochlea or labyrinth and divides it into 2 parts (by the joining of its external wall to the internal wall) or 2 canals (it is very easy to see on a cross section of a turn :

- the upper vestibular canal,
- the lower tympanic canal.

These 2 canals contain another liquid which is slighty different from the endolymph : the perilymph and they communicate at the end of the osseous cochlea (helicotrema).

Each of these 2 canals has a window which opens into the tympanic cavity of the middle ear. It is the oval window for the vestibular canal, closed by the base of the stapes, and the round window for the tympanic canal only closed by a fibrous membrane.

In the organ of Corti finally, each ciliated sensory cell is connected with a nerve ending of the first sensory nerve cell (or ganglioneuron).

B/ Nervous paths of auditory information

The cochlear nerve joins the vestibular nerve (from the posterior labyrinth) to form the statoacoustic nerve or 8th cranial nerve, which together with the facial nerve goes through the internal auditory meatus then the cerebellopontin angle and into the brain stem between pons and medulla. These ganglioneurons (or protoneurons) terminate in the cochlear nuclei in the superior part of the medulla.

The nuclei are made up of the cellular components of the 2nd neurons of the auditory nervous path. There are 2 nuclei :

- the ventral cochlear nucleus
- the dorsal cochlear nucleus.

The axons of the 2nd neuron constitute,the trapezoid body in the center of the pons then pass vertically the lateral lemniscus :

. from the ventral nucleus by crossed fibers,
. from the dorsal nucleus by direct fibers to the ipselateral lemnicus.
. and by crossed fibers which in their horizontal path form auditory striae in the floor of the 4th ventricule and then ascend as the contras lateral lemnicus.

Each band thus contains crossed and uncrossed fibers.

Most of the second neurons terminate at the medial geniculate body, some of them at the inferior quadrigeminal body. After the medial geniculate bodies, we find the 3rd order neurons, the thalamocortical neurons. Their cellular bodies are in the medial geniculate body. The axons form the thalamotemporal tract of Arnold and terminate under the cortex of the lower lip of the Sylvian fissure in the auditory temporal area. (Brodmann's area 41).

A secondary path, the reticular path augments the main sensory path. Its anatomical recognition is not yet perfect. We will study its physiological role.

2. NOTION OF "PHYSIOLOGICAL ACOUSTICS"

Sound perception extends from pure (rare) and simple sounds to complex sounds (voice).

A/ Audition of pure sounds :

A sound is defined by :
. its pitch,
. its intensity,
. its duration.

1°/ Pitch (or frequency) perception

The range of frequencies detected by man varies between 20 cps and 20000 cps (cps or Hertz (Hz) or double vibration (dv) per sec.) : the higher limit decreases with age). Language, for instance, varies between 500 and 2,000 cps.

This differential sensitivity of the ear to frequency (i.e. the smallest frequency variation which is detected by the ear or the increase in dv numbers necessary to perceive a new frequency), Δ F, varies according to the intensity level.

- ΔF on the one hand (frequency differential threshold) varies with the intensity level,
- on the other hand, it is constant (3°/oo or 0.003) for frequencies from 500 to 6,000 ; under 500, it rises up to 1% or 0.01.

The optimum figure for the sensitivity of frequencies is equal to 3 % (it corresponds to 1.3 savart in music, and one semi-tone equals 25 savarts, ΔF is therefore much less than a semi-tone).

2°/ Intensity perception

If the sensitivity of the human ear is acute for the sound frequency variations, the perception of a sound is itself conditioned by its intensity.

For a given frequency, the sound power depends on the vibration amplitude. This amplitude may be expressed by the sound pressure or the sound intensity.

Sound vibrations cause pressure variations both over and under a mean pressure which is the air pressure.

The amplitude of these pressure variations is called Sound Pressure. It is calculated in dynes/cm2 or Baryes.

But the sound propagation is also an energy propagation, in other words, vibrations carry energy. The sound intensity perceived by the ear is the amount of energy communicated per sec. to each unit of surface of the ear drum by the vibrations.

The defined measure is in energy per sec. per cm^2 or power per cm^2. It is expressed in Watt/cm^2.

For instance, the lowest auditory threshold for the F 1,000 cps (i.e. the lowest threshold because it varies with frequencies) is obtained with :

2×10^{-14} baryes, in pressure, that is $\frac{2}{10,000}$ mg/cm^2, that is 10^{-16} Watts of energy.

This is the level of the O in audiometry.

Above the minimal auditory threshold, powers are more easily measured by the substitutionof their logarithm.

The logarithmic scale with the base 10 for bel and decibel was adopted (the decibel is about the lowest intensity variation perceived by the human ear : in fact, the Δ intensity is still lower), which corresponds to Weber-Fechner's law (S = K log.E).

But the ear is less sensitive to low-pitched and high-pitched sounds than to middle

range sounds. The threshold rises both under and above the most favorable frequencies (1,000 to 2,000 cs).

If we represent the curve of the auditory threshold as a function of frequencies and sound intensity, it rises on both sides.

It is the same thing for the maximal auditory threshold or pain threshold, with low and high frequencies which are quickly attained : audition first becomes uneasy, then really disagreeable and finally painful.

Both curves of lower and higher thresholds represent man's sound auditory field.

We see that the field of the ear's sensitivity is quite extended for middle frequencies between both minimal and maximal thresholds.

The ratio of energies between the 2 thresholds is of about 10^{13}, in other words between the lower and the higher sounds, the energy quantity fluctuates from 1 to 10,000 billions.

This is the reason why the sound intensity differences is now expressed in a logarithmic scale,the unit of which is the Bel (in homage to Graham Bell, inventor of the telepone).

It follows that the sound intensity level rises by 1 Bel every time that the vibration energy is multiplied by 10. In practise it is easier to use the decibel or tenth of a Bel.

Finally, we call intensity differential threshold (Δ i) the lowest intensity difference perveived by the ear.

The relative differential threshold (Δ i) varies from 10 to 20 % according to the intensity frequency.

Clinically in audiometry for the recruiting study, we study the pathological variation of the differential threshold (Δ i) with the test of Lüscher and Zwislocki.

To summarize, let us review pure sound audition :

- the ear is very sensitive to the 3°/oo frequency,
- is less sensitive to intensity (3%),
- responses of the auditory system are not linear. All curves of sensation present an identical general form, a central plateau and two rising ends. Weber-Fechner's law applies only for the central zone,
- in practise, it is not sufficient to study the preliminary audition as for the simple tone audiogram, but one must also explore the supraliminal audition within the sound auditory field.

B/ Audition of superposed pure sounds and of complex sounds

Pure sounds are exceptional in life.

We hear :

- superposed pure sounds (equal intensity, different pitches) ;
- complex sounds (3 elements : pitch, intensity as for pure sounds and besides timbre or harmonic "sound composition" ;
- and noise : acoustic vibrations without periodicity.

There are also time elements in the auditory function :

- the frequency perception time of about 1/100 sec,
- the intensity appreciation time (more or less equal to 2/10 sec.),
- the auditory persistance : above 7 recurrencies per sec., sound becomes continuous.

There are also the notions of fatigue and adaptation.

The hearing of the human voice involves the notion of intelligibility, not only as a function of the peripheral perception but also of the cortical integration.

Hearing is finally binaural, which raises the threshold by 3 dB, by 6 dB (to + 40 dB) and makes hearing an orientation faculty.

There is also the bony sound transmission mechanism.

3. ANALYTICAL PHYSIOLOGY OF HEARING OR HEARING MECHANISMS.

Two different successive processes occur in the physiology of hearing.

1°/ The vibratory transmission process which causes the ciliated sensory cells to be stimulated.

2°/ The subsequent perception process : generation of a nerve impulse, its transmission and central integration of the sound sensations.

A/ Vibratory transmission

. in the outer ear :

Nothing difficult to understand here : the auricle directs the sound waves to the external auditory canal and since it is a resonant chamber, it increases the sound pressure.

. in the middle ear :

It has 2 roles :

- transmission and amplification of the sound pressures ;
- protection of the auditory system.

It is necessary for the transmission to be amplified because in going from an air environment to a liquid environment, the sound wave loses 999/1000th of its power, i.e. 30 dB in logarithmic notation. The tympanum-ossicles system recovers these 30 dB.

Protection is assured by the play of the muscles and suspensory ligaments of the ossicle chain.

At the end of the external auditory meatus, sound waves fall on the ear-drum. What is its role ?

It consists in vibrating like a "pressure microphone". The amplitudes of the membrane vibrations vary with the tympanic areas.

The posterior part vibrates more than the anterior part :

A chart of the vibration amplitude contours has been established by BEKESY : they present concentric lines.

The vibration area is enlarged by the conical shape of the ear-drum.

Its active area = 3/4 of the membrane = 55 mm^2.

Behind the ear-drum, there are the ossicles. What is their role ?

DAHMANN has shown by stroboscopic recording that the ossicles also vibrate on different planes :

- the main plane corresponds to movement of the handle of the malleus and long process of the incus about an antero-posterior axis (in the line of the anterior ligament of the malleus and and the short process of the incus).

- movements vary according to the sound wave intensity :

. The chain vibrates like a "solid unit" to weak stimulations.
. With high intensities, most of the energy is lost by differential interosseal movements.

- In the same way, the transmission axes are changed by intensity. With low pressures : the stapes footplate acts like a door with a posterior hinge. With high pressures : the stapes no longer moves in the axis of its larger diameter but in that of its smaller diameter ; its superior hemisphere inserts into the oval window while its inferior hemisphere emerges from the vestibule. Therefore with high intensities, the ossicles protect the internal ear by energy absorption.

- A last but important point : vibrations transmitted through the ossicular chain change phases (this is important for the window play in phase opposition).

The middle ear muscles also have a role to play :

. they protect the ear by contracting ; they reduce the chain mobility with high intensities (painful hypearcusia of facial palsy (FP),

. with low intensities, on the other hand, they permit accommodation : muscular relaxation induces better hearing.

The tensor tympani and the stapedius muscles have a synergistic but antagonistic play. Their mobility is a reflex (the tensor tempani muscle can have only voluntary contractions).

Role of windows :

- by the "ratio of surfaces" Ear-drum/Stapes, the sound energy is augmented by 26 dB for

there is a loss during the transmission through the liquid.

- when it reaches the oval window, the sound energy mobilizes labyrinthine liquids. They are incompressible, therefore there is a need for a decompression window : it is the round window which must, therefore, play in opposition phase with the oval window.

- Round window : passive window
- Oval window : active window.

The last thing for the physiology of the middle ear is the necessity for a good ventilation of the tympanic cavity :

. The 2 cc of air assure acoustic isolation of the chain, so that it is not shaken by the body transmitted noises.

If there is less air, the vibration capacity decreases. The air is renewed by the Eustachian tube and its muscles (a condition for success in tympanoplasty).

Final transmission to the internal ear.

The internal ear contains the receptive sensory organ but this one also plays a role in transmission, as BEKESY showed.

- First, in 1928, on a "cochlea model" (glass box with 2 windows, full of glycerin with thin metal particles, visible under stroboscopic illumination ; a thin metal sheet supporting a rubberized plate simulates the basilemma).

He showed :

- that stapes vibrations cause vibrations of the basilemma ;
- but the basilemma especially responds at a point which varies with the frequency (maximal amplitude point).

For higher frequencies, this point moves to the base, for low frequencies, the point moves in the direction of the apex. It does not change, even if the round window is blocked.

- Then he made the same verifications of the hydrodynamic laws of transmission on "fresh human cochleas". By fixing an immersion microscope in windows made at each level of the turns of the cochlea, BEKESY proved :

. that all labyrinthine membranes move together (i.e. the whole cochlea duct with : basilemma, Corti's organ, tectorial membrane, Reissner's membrane).
. that the maximum point of vibration amplitudes of the cochlear wall moves as a function of frequency (it comes nearer as the frequency increases. The low-ptiched sounds cause a vibration of the apex).
.every frequency has a fixed point of maximal vibration, thus without seeing the "wave trains" on the live cochlea, BEKESY could prove they existed and even measure the wave propagation velocity in the cochlea.

This work and further research permitted determining the chart of tone localizations (frequency localizations) on the basilemma.

Frequency discrimination is, first of all, an hydrodynamic process.

PHYSICAL SYNTHESIS OF THE TRANSMISSION FUNCTION : Notion of impedance.

Physically, the ear can be compared (as to its transmission function) to an oscillator, the restoring force of which is dyssymmetrical and dampened.

Such a physical assimilation leads one to contemplate the notion of impedance which is the vibration resistance in a vibrating system.

The following elements are involved in the resistance :

. mass of the apparatus (m)
. stiffness (s)
. rubbing (r) (or displacement resistance).

m and s are two factors with adverse effects called Reactance, the formula of which is :

$$\text{Reactance } R = m.f - \frac{S}{f} \quad (f = \text{variable frequency})$$

If $m.f = \frac{S}{f}$, the 2 factors are counterbalanced, it is the resonance point.

It is possible to build the parallelogram of these antagonistic forces (m and s) ; it is the graphical representation of the impedance elements : reactance = a vector perpendicular to Rubbing (r), the hypotenuse Z^2 equals the result of the combined actions of reactance and rubbing ; it gives the final result of interactions and represents impedance.

Its formula is : $Z^2 = R^2 + (m.f - \frac{S}{f})^2$ or $Z = \sqrt{R^2 + (m.f - \frac{S}{f})^2}$

The formula can be clinically applied :

- Transfer through an oscillator changes the phase of the incident wave (what happens in the ossicle chain).

- The formula permits calculating the result of the variation of the various elements.

m = tympanum-ossicles structures and labyrinthine fluids.
s = muscles, ligaments, tension of window's ligaments.
r = freedom of movements of the tympanum and the fluids.

(m for instance increases in exudative otitis),
(s increases in ostopongiosis),
(r increases in labyrinthine hypertension)
(Meniere's disease)

If s increases, the energy loss will be acute for the low frequencies, since s is divided by f, which happens at the beginning of otospongiosis.

If m is increased, the loss will be especially marked for high frequencies since m is multiplied by f... etc...

In spite of the theoretical character of the notion of impedance, we see that it is an interesting attempt to rationalize the biophysical problem of sound transmission.

These theoretical notions have found a practical application in impedance-audiometry. Its clinical interest is important in compliancemetry, tympanometry and stapedial reflex.

B/ Sound perception

- Neurosensory perception
- Message integration
- Auditory cortex

Neurosensory perception :

Nervous energy is a modified potential along the nerves. We tried to demonstrate the electrical activity generated by auditory perception.

1896 : a variation in potential was detected on the auditory nerve by BEAUREGARD and DUPUIS. Little progress was made then until 1927.

1930 : WEVER and BRAY performed a rather extraordinary experiment on a cat's ear and showed that the ear reacts like an intermediary microphone. The same result is obtained by fixing electrodes on the cochlea itself, therefore the cochlea functions like a microphone and there is "a cochlear microphonic effect". (What was recorded by WEVER on the nerve itself was an artefact of diffusion of the so-called "microphonic effect").

ANDRIAN, BRONK, DAVIS, and SAUL could separate the 2 phenomena and record them separately :
- the microphonic effect on the one hand,
- the variations in the potential of the nerve impulse of the VIIIth nerve on the other hand.

The cochlear microphonic effect - its characteristics

The cochlear microphonic effect was found in all animals and in man during interventions (Lempert) : "cochleograms".

Physical and physiological characteristics of the cochlear microphonic effect :

a)- Potential variations are low (a few microvolts) ; they must be amplified for study.

. Low-pitched sounds vibrate the whole cochlea and we can record their microphonic effect in all four turns.

. The base is sensitive to any frequency but especially to the high-pitched sounds (DAVIS, TASAKI, LEGOUIX).

b)- The microphonic effect has no threshold : it does not follow the all -or- none law like the nerve fibers. For low and middle intensities the microphonic effect exactly reproduces the sound wave shape.

c)- The latency of the microphonic effect is very short : 0.1 thousandth of a sec. (0.7 thousandth of a sec. for the nerve potential.

d)- If the phase of the sound stimulus is inverted, the polarity of the microphone is also inverted.

e)- The microphone effect reproduces the imposed frequency (up to 100,000 cps for the bat, whereas the frequency of the nerve impulse action potential cannot exceed 1,000 cps

limited by the refractory period of nerves.

f)- Therefore, the microphonic effect is not exactly a nervous phenomenon. Its nature is more phsyical than physiological. It is only the almost immediate tranformation of mechanical energy into electrical energy. The cochlea must be intact and the effect decreases in case of a sound trauma. It also depends on certain biological conditions. It is reduced by anoxia, e.g. by ligature of the external carotid, or by excitation of the sympathetic nervous system. It only progressively disappears from 0 to 1 hour after the death of the animal (whereas the nerve potentials immediately disappear).

The origin of the microphonic effect is arguable :

- vibration of the basilemma ;
- deformation of the cilia when the basilemma vibrates : piezoelectric effect ;
- BEKESY : 2 sources
  . the piezoelectric mechanism of the ciliated cells,
  . change in the electrical resistance of the basilemma membrane depolarization.

Role of the cochlear microphonic effect

It is the intermediary link between the mechanical vibration of the labyrinthine structures, and exactly mirrors this as well as the stimulation of the nerve endings.

The cochlear microphonic effect discovered by WEVER and BRAY allowed one to study objectively the cochlear reception in the experimental animals and to measure hearing in animals, and to establish audiograms whose value is superior to those obtained by the conditioned reflex method. Thanks to the cochlear microphonic effect, a great step forward has been made in the study of the problem of frequency localizations (formerly foreseen by Helmholtz). The corresponding chart could be established.

Generation of the nerve impulse

The cochlear microphonic effect is not the nerve impulse. Where is this impulse generated ? and how ?

It is generated at the base of the ciliated cells at the point of contact with the dendrites.

There is a first immediate deflection due to the cochlear microphonic effect on the curves, produced by a click of white noise.

After a latency of 0.53 to 0.84 thousandth of a sec., there are then the successive deflection waves of the nerve impulse.

In the course of microphonic recordings, DAVIS and FERNANDEZ demonstrated a unidirectional component due to the depolarization of the auditory filaments at the level of the Corti cells corresponding to the summation potential, which is strictly local, dies on the spot but communicates the elements which generate the impulse and transfer it to the fiber.

What is the nature of this "summation potential" ?

- mechanical ? (vibration)
- electrical ?
- chemical ?

A chemical mediator is likely here, by analogy with the eye in which the retinal purple converts the physical energy into nerve impulse.

Anyway, the nerve impulse appears in the terminal fibers which cap the base of the ciliated cells ; it then follows the fibers of the auditory nerve (32,000 fibers). Electrodes placed on the VIIIth nerve itself allow its recording.

Nerve message and transfer action potential

Message in the cochlear protoneuron

The action potential which are recorded at the level of VIIIth nerve present characteristics which are quite different from the cochlear mirophonic effect.

1935 - The recording microphonic effect was eliminated by DERBYSHIRE and DAVIS by the use of coaxial electrodes. The message can be followed along the paths up to the nuclei.

1943 - GALAMBOS and DAVIS could record the activity of one or few isolated fibers with microelectrodes of 3 μ in diameter. The activity of the fibers of the first neuron could be observed and we could see that considering the functional specialization of each fiber, this activity generally follows the laws of the nervous physiology.

Characteristics of the message in the auditory nerve (nerve action potential)

a)- General characteristics (these characteristics are different for the nerve action po-

tential and the microphonic potentials.

- Latency : from 0.7 to 0.9 millisecond.

A liminal intensity is also necessary here as it is for all other nerves.

If the intensity of the stimulus is increased, the response rise is not parallel.

- Refractory period (as it is for all other nerves) : 1/1,000th of a second. Any nerve has an impulse rate which cannot exceed 900 to 1.000 cs

However, in the physiology of the VIIIth nerve, we tried to find a rate reproducing the sound vibration in the impulse rate. This is not exact.

In fact,

- The frequency is known by the specificity of the nerve fibers, at least above the low-pitched sounds. There are fibers which respond to a certain frequency reproducing the rate of this frequency.

- The intensity is recognized by a rise in impulses in the already specialized fibers for this frequency and for which there is no possible confusion and also by the increase in the stimulated neurosensory area (thanks to the number of the simultaneously stimulated adjacent fibers).

b)- Own characteristics

Quasi specifity of the fibers to the frequency. Each relaxed neuron has a permanent (rest potential) basic electrical activity (spontaneous slow rhythm).

For each of the neurons, there is a threshold which permits producing an activation (potential of action) which causes a stimulation rhythm with discharges of potential of accelerated action.

GALAMBOS and DAVIS demonstrated that at the threshold, each neuron only gives a response to a very narrow frequency band.

If intensity increases, the neuron reacts to a wider and wider frequency band. But it broadens only towards the low-pitched sounds, and almost not at all towards the high-pitched sounds. It is wider with neurons which react to low-pitched sounds. The high-pitched sounds reactive neurons are more selective and only let through the high-pitched sounds. The middle neurons also extend towards the low-pitched sounds.

Therefore, each neuron fits for a determined frequency, under which it gives the highest number of action potential per second.

If intensity increases, impulses increase in the isolated fiber up to 35 dB. If intensity increases by more than 35 dB, the potentials of action of adjacent fibers also increase.

The frequency differential thresholds and the intensity differential thresholds in the fibers have been assessed. The conduction speed in the fibers of the VIIIth nerve equals 30m/sec., a result obtained by the study of spikes caused by a click of white noise on different levels.

The protoneuron message terminates in the ventral and dorsal medullary nuclei where there is a spatial localization :

. The high frequency specialized fibers are located on the sides ;
. The low frequency specialized fibers are located in the median part of the nuclei.

Message in the bulbothalamic deutoneuron

We know less about it :

- latency :
  . at the level of the trapezoid body : from 2 to 3 milliseconds ;
  . at the level of the inferior quadrigeminal body : from 4 to 5 milliseconds.

- rhythm : it decreases as we reach a higher point in the nervous system.

- at the I.Q.B. level, there is no rhythm higher than 500 cps.

The potential amplitude decreases with the rhythm (diffusion and multiplication of the synapses).

The localization of frequencies was made by COPEE-DAVIS in the cat.

Besides, there are associative paths in the 2nd neuron which are at the origin of the auditory responses and of the auricular interdependence phenomenon.

Message in the 3^{rd} neuron, the thalamo-cortical neuron

We have few neuro-anatomical and neurophysiological data at our disposal.

The metathalamus or median geniculate body MGB is joined to the thalamus which is the last joining point of all the sensitivosensory systems except for olfaction.

There is a spatial organization of f in the M.G.B.

A chart was established after the study of localized destruction in conditioned animals, for the recording ot the action potential in the geniculate body is difficult.

Man's auditory cortex is not well known because the auditory afferents are received equally bilaterally whereas the pathological lesions are most of the time unilateral.

Studies have been performed on animals : monkeys, cats and dogs.

The fundamental auditory focal area in man corresponds to the HESCHL gyrus (superior face of the temporal lobe) which corresponds to the middle ectosybian convolutions in animals : primary area (Area I) limited by a secondary area (Area II) and a frontal third area (Area III).

CONCLUSION.

The auditory graph and its integration.

Once the message has reached the cortical areas, it is integrated by the cerebral activity.

The auditory graph can be reduced to its basic points :

1) the sound wave reaches the auricle and the external acoustic duct which can be compared to a resonance chamber. The wave vibrates the tympanoossicular oscillator. The internal ear is protected by the play of articulations and muscles. The energy loss due to the passage of the sound wave in a liquid is compensated by the hydraulic ratio or surface ratio (of the ear-drum and the oval window).

The transmission continues into the internal ear. The fluids and the cochlear membranes are vibrated according to the hydrodynamic laws which ensure the selective stimulation of the specialized parts of the basilemma.

2) The specialization of the nerve fibers follows the spatial localization of frequencies in the cochlea. They follow the general laws which concern the neuro physiology. Their action potential is not a reproduction of the frequency. Three neurons rise in tiers from the receptor to the cortex. The rhythm of impulses is lower because of dispersion and synapses.

At the level of the cortical areas, we find again -as in the medullary nuclei at the metathalamus- spatial localization and nerve specialization which we already found in the cochlea.

3) The message reaches the brain under the form of a rhythm with no relation to the sound frequency which caused it.

The cortex can recognize the message because it is "coded". In short, the integrative function of the cortex is a decoding function. This conception results from the theory of information, which is itself a part of cybernetics.

AVIATOR HEARING LOSS

by

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The combined effect of aural and acoustic barotrauma has, for a long time, induced mixed hearing losses for low speech and high speech frequencies, these being necessary for speech intelligibility.

Currently, aircraft pressurization has lowered the incidence of barotrauma.

However, flying personnel are still literally "immersed" in a sound trauma environment which finally has been taken seriously in the past few years.

Let us recall a few revealing numbers :

- At a distance of 1 m (3.3 feet) from an aircraft engine bench, the sound level exceeds 125 dB.

- In a boeing 747 flying at a cruising speed of mach 0.8 and at an altitude of 35,000 feet, the sound level recorded around the pilot's head reaches 80 dB. This level increases notably during take-off and landing.

We have always found it extremely difficult to obtain information from aircraft constructors about the sound levels in the various parts of the aircraft !!

Today we know the critical noise level : it ranges between 90 - 100 dB and is all the more dangerous in that it contains more of the high frequencies ; the danger increases with exposure time, which is a significant factor : a French fighter pilot terminates his carreer with 8 to 10,000 flying hours, at 50 years of age. A civilian pilot of the same age totals 20 to 25,000 flying hours.

- The aviator's hearing loss appears today, in most cases, to be the result of sound trauma, impairing more or less symetrically bilateral perception, without inducing any other symptoms.

- Tinnitus, which frequently occurs in acute sound trauma is relatively rare in this case.

- This hearing loss is relatively well tolerated by the subject, at least during all his professional life.

CLINICAL EXAMINATION.

1/ OTOSCOPY shows a closed ear drum, most often mat. Its mobility during examination with Siegle's otoscope is variable, though most often reduced.

2/ ACOUMETRIC EXAMINATION has little significance at the early stages. The 4,000 Hz tuning fork is less acutely perceived. Speech acoumetry reveals mistakes in the perception of high frequency tones.

3/ SOUND AUDIOMETRY is the most important and indispensable test :

. at the initial stage hearing hoss appears between 2,000 and 6,000 Hz, at 20-30 dB (V at 4,000 Hz). In many cases, the curve remains the same for several years, thus appearing to have stabilized.

. the loss increases by steps, in an unpredictable manner :

- the loss increases
- the range includes high and low frequencies.

. the loss often occurs abruptly during the first years of professional life and later stabilizes.

The magnitude of the loss depends on flying personnels's function and work place in the aircraft :

- flight engineers and radio-navigators suffer from hearing loss more often than pilots, stewards or stewardesses.

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- hearing loss is often greater for military pilots than for civilian pilots.

Dysfunction of the eustachian tube should not be overlooked. It encourages micro-barotrauma and sensitizes the cochlea to sound trauma.

It is also obvious that certain factors of individual susceptibility also play a role, which are unfortunately impossible to test : in one case, hearing will deteriorate quickly while in another case, under identical conditions, it will resist a lot better.

It should be remembered that the pilot's hearing loss presently appears as a more or less symmetrical drop in bilateral perception, most noticeable for the high frequencies of the audible spectrum and possibly running into speech frequencies.

Some atypical forms are more rare :

. lesions mostly affecting the medium frequency range (1,000 - 2 ,000 Hz) ; in this case social communication is more noticeably affected.

. unilateral forms or forms with a strong unilateral dominance : in this case another etiology will be considered, i.e. viral, endotoxic or, especially, acoustics neurinoma (X-ray of internal auditory tube).

Paradoxically, on the professional level, annoyance often remains minimal ; this is confirmed by speech audiometry tests under silence and noise conditions ; sentence intelligibility remains satisfactory for a long time, which allows us to keep these subjects in active service without endangering flight safety. Various factors come into play : cortex compensation, use of microphone as hearing aid.

It is often at the time when flying personnel stop their profesionnal activities that hearing problems start becoming more objective.

HEARING LOSS FREQUENCY IN FLYING PERSONNEL.

It is difficult to know exactly the number of personnel suffering from hearing loss, especially as the loss revealed by tone audiometry often does not reflect the level of interference with social communication.

We can state with certainty that past 50 years of age (end of the active professional life of flying personnel) hearing loss for high frequencies is always greater than that of a control group which has not been exposed to sound trauma.

The ear of a 50 year old flying individual is most often in the same condition as the ear of a 70 year old non flying individual, which means that ear senescence begins, in this profession, 10 or 20 years earlier than for non flying personnel.

As there is no therapy presently available to remedy this type of hearing loss in the inner ear, it is easy to conceive how important it is to prevent such a loss.

PROPHYLAXIS.

Prophylactic measures must be implemented on two levels :

1/ flying personnel :

. strict selection of applicants :

- any pre-existing lesion in the inner ear, whatever its cause, must qualify the applicant as unfit.
- any malfunction of the eustachian tube favoring barotraumas which make the inner ear more sensitive must also qualify the applicant as unfit.

. regular medical check-ups of the pilot :

Any acute inflammatory affection of the nose-tube-inner ear complex must be a mandatory cause of temporary interruption of flying activity.

2/ aircraft design :

The problem is to decrease the noise levels at the noise sources. This is not only an engineering and financial problem, but also a problem of man's frame of mind.

"Noise does no good ; good makes no noise". (Saint Vincent De Paul)

PHYSIOPATHOLOGY OF EQUILIBRATION IN AEROSPACE MEDICINE

by

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1. PHYSIOLOGY OF EQUILIBRATION (REVIEW)

The physiology of equilibration is relatively complex. The confusion already starts when one wants to define equilibration : no definition is perfectly satisfactory.

Equilibration is, of course, the function which maintains equilibrium. However, bodies are subjected to different forces on the ground and in the air :

- gravity (except in weightlessness),
- inertial force,
- kinetic force,
- centrifugal force.

A more precise definition of equilibrium would then be : "the state in which the resultant of the set of forces influencing a body falls within its support plane".

This definition is, however, incomplete as it is all physical and not at all physiological.

From a physiological standpoint, THOMAS defines equilibrium as "immobility in the maintenance of an attitude". Even this definition is still not quite satisfactory : maintaining an attitude actually requires the ultra-rapid intervention within 100 ths of a second, of nervous reflex mechanisms, all aiming at a muscular adjustment.

Equilibrium can therefore be defined as "the maintenance of a correct static or dynamic attitude by adequate tonic or clonic (phasic) adjustment of the muscular network".

A muscular adjustement is the fundamental component of equilibrium, it is may be worthwhile to first review a few notions concerning MYOGENIC TONUS (MT).

Myogenic tonus is the "slight tension of the striated muscles at rest which disappears when motor or their corresponding posterior medullar roots are severed".

The tonic contraction does not generate any movement. It is a postural activity of the muscles which sets the joints of the skeletal pieces in determined, interdependant positions and which defines a global attitude.

Tonus and its distribution thus vary according to the posture.

MT originates in the muscle itself, as the study of the myotatic reflex or "stretch reflex" shows. This reflex is described by SHERRINGTON and LIDDEL (1897) : the muscle, provided with its own nervous system, reacts to a moderate stretch by a contraction proportional to the imposed stretch.

This stretch reflex is a medullar reflex. The sensory and motor roots corresponding to the considered muscle must be undamaged.

The receptor of this stretch is neuromuscular spindle, a deep proprioceptor, located in the muscle itself. The reflex arc is medullar.

LLOYD has shown that its efferent pathway not only reaches the motorneurones of the stretched muscle, but also those of the agonist and antagonist muscles. It stimulates the former and inhibits the latter.

The myotactic reflex thus provides a system of adjustment of the tonus of a group of muscles as a function of posture. It is easy to imagine the important role of this function, fundamental to all posture and equilibration phenomena. It is the "primum movens" of the standing position in man and animals.

We do not intend to go into the details of the mechanism of the spindle system and muscular-tendinous proprioceptors. We will only describe them briefly to give an idea of this mechanism (thoroughly investigated in the electrophysiological studies of MATTHEWS and HUNT) since it is the very basis of equilibration. Let us consider a muscle motor unit, and next to it, a neuromuscular spindle (NMS). Both are connected by the same tendon at the bottom. The NMS is a very small independant muscle called "intra spindle muscle", located within the mass of muscular fibers. It has a special sensitive system made of annulospiral fibers (fibers Ia) and bunched fibers (fibers II). The tendon has another sensitive system called GOLGI's corpuscle (with its fiber called fiber I b).

These three systems are sensitive to stretching which is their physiological stimulus (fibers I a especially, with a threshold of 3 g in the cat). These three types of fibers are connected in the marrow to the alpha motor fibers of the muscle which thus contracts : it is the myotatic or stretch reflex.

However, the alpha motorneurons represent only 2/3 of an anterior root. The remaining 1/3 is represented by the gamma motorneurons which control the small intra spindle muscles and thus can also, by inducing a spindle contraction, stimulate the sensitive Ia and II endings and trigger muscular contraction.

The gamma motorneuron and the posterior radicular Ia and II neurons form a loop called gamma loop, which controls the alpha motorneurons. But what is more : the gamma activity is constant (under reticular control) and it is precisely this activity which, by a slight constant spindle contraction, ensures basic permanent stimulation of the alpha system, thus ensuring basic muscular tonus.

Consequently, the muscular tonus which is the basic condition of attitude, hence of equilibrium, is regulated by the activity of the gamma loop of the spindle proprioceptor.

Although the NMS is a basic condition of equilibrium as the provider of myogenic tonus, it can also be found in muscles which do not play any role in equilibration, e.g. the muscles of the soft palate, of the eustachian tube, of the malleus, etc... In such muscles, spindles only provide their own tonicity.

We have thus defined the basic condition of equilibrium, i.e. MT. However, the muscular reflex function, i.e. regulation of equilibrium achieved on the one hand by tonic muscle contractions and, on the other hand, showing potentially phasic characteristics depends on other mechanisms which we shall study in detail in EQUILIBRATION PHYSIOLOGY per se.

It seems, at first sight, that static position requires only a minor muscular effort. So minor that it has remained unsuspected for a long time : it was thought that the various pieces of the skeleton held up under the sole effect of the articular ligaments. However, in 1867, DUCHENNE and BOULOGNE demonstrated the indispensable action of muscles.

Animals at rest take a "fundamental" attitude which meets the physical necessity that the center of gravity be projected on the support surface. It varies according to the species, so as to require the minimum possible muscular effort.

The position of the head, information and control center, is critical : if a body movement alters the position of the head, a corrector reflex sets it back in the correct position.

The equilibrium position of the head is the first position obtained in "erector" reactions. Only when the head has recovered its correct position can the rest of the body and the limbs erect.

The trunk and limb muscles are used to maintain the head's position.

Besides normal equilibrium, man or animals can acquire, by acrobatic or sport training, a "luxury" equilibrium where powerful muscular efforts correct the positions when it seems impossible to achieve equilibrium.

The special equilibrium acquired by the pilot and especially by the astronaut in their air or spacecraft should be related to this luxury equilibrium achieved on the ground.

The physiology of equilibration is a REFLEX PHYSIOLOGY : it is the study of a set of reflexes or automatic reactions which are traditionally easy to class in three groups :

- static reflexes,
- erector reflexes,
- equilibration reflexes per se which are obviously interconnected and often interdependant.

All these reflex reactions are triggered by excitations or stimuli of specific receptor systems which should be studied before commenting very briefly the reactions themselves, then the respective value of the different reflexogenous systems and finally, the role of the central nervous system in equilibration.

1/ The three reflexogenic sensory systems which regulate equilibrium

Where are afferent reflexes which control and maintain equilibrium actually generated ?

Primarily, in three groups of sensory receptors :

- vestibular receptors (or cephalic proprioceptive receptors),
- deep proprioceptive receptors (or somatic proprioceptive receptors),
- visual receptors,

to which a 4^{th}, but much less important group should be added :

- exteroceptive receptors (sensitive, cutaneous).

We shall first study the VESTIBULAR RECEPTORS. Their excitations are, if not essential, at least very important for the regulation of equilibrium.

A very brief anatomical review is necessary to understand their action :

These receptors are located in the posterior membranous labyrinth or vestibule, itself located in the posterior osseous labyrinth, i.e. the posterior part of the inner ear (the anterior labyrinth or helix contains the cochlea).

This membranous vestibule essentially contains :

- a small membranous sphere, the utricle, connected by the endolymphatic canal to a smaller sphere located in front of it (and very secondary in man), the saccule.

Our three spatial antennas are connected to the major part of this vestibule, the utricle. They are the horse-shoe shaped semicircular canals, each located in a spatial plane : one horizontal or external plane (actually 30° above the horizontal plane) and two vertical planes :

- an anterior or superior plane,
- a posterior plane.

These canals are perpendicular to each other. At its insertion point in the utricle, each canal is dilated in a flasklike shape : the canal ampulla.

All these membranous formations contain the same fluid, the endolymph and bathe in the perilymphatic fluid contained between the osseous labyrinth and the membranous labyrinth.

Each bulb of the semicircular canals contains an important sensory component : the ampullar crest, made of a structure of ciliated sensory cells arranged in the shape of a dome, dominated by a sugar cone-shaped mucoproteinic and mucopolysaccharidic gelatinous mass, the cupula, whose summit touches the top of the bulb.

The cilia of the sensory cells penetrate into this cupula which has an extremely light specific weight and is, at rest, in equilibrium in the endolymphatic fluid.

At their base, these sensory cells are in synapsis with the ganglionic protoneurons, which together form the ampullar nerve. This nerve reaches Scarpa's ganglion where the three ampullar nerves meet and form the vestibular nerve.

The utricle and the saccule each contain a layer of ciliated sensory cells of the same type forming the macula, whose cilia penetrate into a membrane extending over the macula, with the same constitution as the cupula, but whose specific weight is increased here by otoliths (crystals of calcium carbonate) : it is the otolithic membrane.

This membrane is immobile at rest and stays in equilibrium in the endolymph. Each cell is also connected by its base to a ganglionic neuron, which together form the utricular nerve and the saccular nerve which also reach the vestibular nerve.

What is the nature of vestibular stimulation ?

EWALD showed, for the first time, that it was the displacement of the endolymphatic fluid.

By an opening in the external osseous canal, he showed that the pressure which causes an ampullopetal fluid displacement induces nystagmus on the side of the canal, deviations of the head and body toward the opposite side, whereas aspiration which causes an ampullofugal current causes a homolateral fall and an opposite nystagmus. The pressure generates an excitation, the aspiration causes an inhibition. The direction of the reactions is reversed in the vertical canals.

EWALD thus formulated the laws on the endolymph displacements which carry his name and the semicircular canals are recognized from his work and that of FLOURENS to be reacting to the fluid movements (resulting from the inertial force) generated by the angular movements in any spatial plane. The responses show that they also regulate the myogenic tonus of the muscles on their side : the stimulation of an ampullar crest of a canal causes an increase in the tonus of the homolateral muscles (except for the eyes where they also control the opposite external right muscle plus the right homolateral internal muscle).

The movement of the cupula which oscillates on the ampullar crest has been studied and microfilmed by STEINHAUSEN, DOHLMAN and LEDOUX.

The increase and decrease (until total inhibition) in the basal electrical activity of the canals have been precisely described by LEDOUX who recorded the nervous currents of action during rotary stimulation.

KLEIN, MAGNUS and QUIX were the first to consider the utricular maculae to be the cephalic proprioceptors of linear and slow head movements, giving information about the position of the head in space.

They are therefore used partly for dynamic equilibration and partly for static equilibration (whereas the semicircular canals are only used for dynamic equilibration), owing to the fact that the otolithic membrane has a higher specific weight than the cupula. The cupula remains immobile in slow tilting movements, whereas the otolith tilts and induces a ciliary traction.

We shall not discuss the saccule as an organ of equilibration since, experimentally, it only responds to vibration. As it is phylogenetically very close to cochlea, ARSLAN and other authors think that it is sensitive to infra-acoustic vibrations (is it not located directly under the oval window when a platinectomy is performed ?).

How are the nervous vestibular influxes conveyed, which generate vestibular reflexes ? They are conveyed by VESTIBULAR NERVOUS PATHWAYS which we must study in order to understand and interpret the labyrinthine responses : their complexity is only apparent. A simple description will make them easy to understand :

When the vestibular nerve emerges out of the internal auditory canal where it is connected to the cochlear nerve (and near the VIIth nerve), it crosses the pontocerebellar space and enters the brain stem between pons and medulla.

As soon as it enters, it is divided into five branches reaching the five vestibular nuclei :

- four bulbous nuclei :
  - DEITERS' nucleus
  - BETCHEREW's nucleus
  - ROLLER's nucleus
  - triangular nucleus
- one cerebellar nucleus :
  - the muscles of the roof of the cerebellum.

The first afferent (or ganglionic) neurons end in these nuclei.

They are in synapsis with : <u>on the one hand</u>, the second afferent neurons (bulbothalamic neurons) which are connected inside the thalamus medial geniculate body) with the third thalamo-cortical neurons. This is the vestibulo-thalamo-cortical pathway (direct and crossed) which reaches the temporal cortex where there is conscious sensation of displacements in the vestibular area close to the auditory area (and potentially conscious regulation of equilibrium), and <u>on the other hand</u> NEURONS of very important CONNECTIONS which form the direct and crossed VESTIBULAR REFLEX PATHWAYS.

These connections reach :

- the cerebellum,
- the anterior horn of the spinal cord,
- the reticular substance,
- the thalamus,
- the oculomotor nuclei,
- the vegetative nuclei.

a) <u>The cerebellar connections are both</u> :

- afferent :
  . by the nucleus of the roof
  . by certain other nuclei (DEITERS) and
- efferent :
  . towards the anterior horns of the cervical spinal cord (which shows the important function of the cerebellum in the cephalic equilibrium).

b) <u>The connections with the anterior horns</u> of the spinal cord are direct, especially through two tracts :

- the lateral vestibulospinal tract which reaches the medullar motorneurons at all levels,

- the median vestibulospinal tract which emerges out of DEITERS', ROLLER's and the triangular nuclei and reaches the motorneurons which control the neck muscles (already controlled by the cerebellum, and thus subjected to double vestibular influences. This shows the important role of head posture in equilibrium).

These spinal efferent explain the essential role of the vestibule in the muscular regulation of equilibrium.

c) We have seen the connections reaching the thalamus, since the thalamus is on the ascending cortical pathway. The thalamus contains a real sub-cortical vestibular center which ensures the thalamo-strio-rubric coordination of automatic movements (MUSKENS) (sensomotor coordination for equilibrium).

d) Reticular connections : ARSLAN thinks that the reticular bulbar connection contains (especially in the gigantocellular nuclei) nuclei which are real centers of ocular nystagmus. In any case, they have a facilitatory effect on the vestibular reflexes. In addition, we have also showed that they regulate the activity of the neuromuscular spindles.

e) Oculomotor connections : they are the PATHWAYS OF NYSTAGMUS. The vestibular nuclei are connected to the nuclei of III, VI, IV, to the intermediate nucleus, to DARKSCHEWITSCH's nucleus, and to the red nucleus, by the medial longitudinal bundle.

There is a direct pathway (direct vestibulo-mesencephalic pathway) and a crossed pathway (crossed vestibulo-mesencephalic pathway).

These pathways explain the relationship between the semicircular canals and the oculomotor muscles (the external canal, for example, controls the right homolateral medial muscle and the right controlateral external muscle). This action is performed in the same direction of activation or inhibition as the other muscular somatic actions, but in this case a rapid WARNING JERK is generated : nystagmus, which prevents deviation.

(We shall leave aside the pathways of vegetative connections which have no interest here, e.g. those reaching the pneumogastric nuclei).

It seems, therefore, that through this system of central connections, the labyrinthine sensibility to various positions and movements is organized both :

- as a reflexogenous sensibility whose effectors are the oculomotor and medullar motorneurons at all levels,
- as a sensibility conscious of its movements in BRODMANN's areas 41, 42, and 52.

The second reflexogenous regulatory system of equilibration is that of ACTUAL PROPRIOCEPTIVE STIMULATIONS, which are the sensory components of muscles, tendons and articulations as well as the ensuing stimulations.

These stimulations occur :

- in the articulations where the articular capsules and the periosteum contain nerve endings which are sensitive to pressure and traction when the body's support or attitude changes,
- in the muscles and tendons, by the sensitivity of the neuromuscular spindles and GOLGI's corpuscles which we reviewed when describing the myogenic tonus.

These excitations are generated when the ground support or the position of the various parts of the body vary (somatic proprioceptive excitations) and when the head position changes in relation to that of the trunk (cervical proprioceptive excitations).

These proprioceptor influxes trigger a double reflex action :

- direct medullar reflexes which induce segmentary reactions,
- cerebellar reflexes which induce the supra-segmentary reactions of automatic postural correction by the spinocerebellar tract which conveys the deep unconscious sensibility toward cerebellum, then by the dentalo-rubro-thalamic tract which ensures motor correction. (We observe, here, a second intervention of the cerebellum. Already involved by the vestibular pathways, it is also involved in this regulation by the deep sensory pathways).

The third regulator system of equilibration is generated by VISUAL EXCITATIONS : it is VISION.

Vision is a very efficient component of equilibration with its perceptive content which gives immediate information about an attitude or position of the body.

It also plays a role by its conditioning in acquired reflexes as erector reflexes for example.

ROMBERG's test clearly shows the role of vision in equilibration : the subject who exhibits a labyrinthic deficit falls only if he closes his eyes.

For the time being, let us remember the important role of vision which we shall later discuss in greater detail.

The last system involved in equilibration is the EXTEROCEPTIVE EXCITATIONS, i.e. the cutaneous receptors. This system plays a minor role in this reflexogenous regulation. This role is very limited in mammals but more important in the lower species : for example, if a frog's leg is dismembered, the myogenic tonus is greatly reduced.

2/ Induced reflex responses

After reviewing the systems which regulate equilibrium, we can now briefly describe the REFLEX RESPONSES produced by their stimulation :

We have agreed to follow the classical pattern and divide them into three groups :

- static reactions,
- erector reactions,
- equilibration reactions per se.

We cannot describe here, in detail, the study of these reflexes such as it was carried out with a lot of graphic and iconographic details by RADEMAKER and MAGNUS in the 1930's.

The first group of reactions include support reflexes and static adaptation reflexes (example : if the flexor tendons of the legs of an animal are stretched, they stiffen and their myogenic tonus increases. It becomes difficult to flex them. It is a support reflex).

The refexes of static adaptation include, among others, the adaptation to load and the adaptation to the head positions (the changes in head position induce a change in the myogenic tonus of the legs or of the body).

The second group of reactions includes the erector reactions (or reflexes) -for example : a cat held in the air in any position always brings its head up (these are labyrinthic and visual reflexes).

The third group of reactions includes the equilibration reflexes per se (or reactions of dynamic adaptation).

These also include corrective movements.

These are generated :

- in the proprioceptive receptors of the limbs for position changes disturbing equilibrium,
- in the labyrinthine receptors for mechanical forces which alter equilibrium.

The former reflexes, i.e. the proprioceptive reflexes generated in the limb muscles, include the tilting reflex (or Schunkel Reaktion of RADEMAKER) the bending reaction (Stemmbeinreaktion) and the limping reaction (Hinkebeinreaktion). These three types of reactions persist in labyrinthectomized or decerebrated animals.

As to the latter reflexes, i.e. the labyrinth induced reflexes, we have already seen that the labyrinth plays a role by the utricular otoliths in static equilibration and in straight kinetic equilibration (during linear accelerations), and by the semicircular canals in the rotatory kinetic equilibration (during angular accelerations).

In man, the reflexes of the semicircular canals can be observed in BARANY's test, performed in a rotary chair, for example :

When the chair rotates clockwise, the right cupula is stimulated at the beginning of rotation by the inertia of the endolymphatic fluid ; when rotation stops, the left cupula is stimulated.

These reactions last as long as the cupula remains deviated. It oscillates on its own basis as a torsion pendulum which stops gradually. (LEDOUX has shown this very clearly by simultaneous recording of ampullar nervous action potentials and filming of the cupular movement).

These reactions are :

- a nystagmus directed to the stimulated side (left, at rest for instance, in a clockwise rotation),
- the segmentary deviations of the body toward the contralateral side (toward the right when a clockwise rotation stops).

The reaction threshold varies, according to various animals, from 1°/sec/sec to 2°/sec/sec of angular acceleration or deceleration.

It is more difficult to study reflexes of utricular (otolithic) origin. However, they can be studied by observating the elevator reactions which show, in the animal for example, an increase in the support tonus and an extension of the neck during the downward motion, a decrease in the support tonus and flexion of the neck during the upward motion.

GREINER has observed in man a deviation of the eyes and a segmentary deviation when the subject is seating in an ascending or descending chair. The values of the reaction threshold in man vary between 4 and 12 cm/sec^2 for the vertical accelerations, and between 2 and 20 cm/sec^2 for horizontal linear accelerations.

3/ Respective value of the three reflexogenic systems

We have reviewed the origin of equilibration reflexes and (although too briefly) the

induced reactions. A question arises : WHAT IS THE RESPECTIVE VALUE OF EACH OF THESE SYSTEMS ? Does the vestibular system play a more important part than the muscular-tendinous proprioceptors or vision, or is it the opposite, i.e. is vision predominant ?

To answer these questions one observed what happens in man or animals deprived of one these systems.

Suppression of the labyrinths causes serious disorders, both in man and animals : labyrinthine ataxia.

Unilateral labyrinthectomy induces loss of myogenic tonus on the homolateral side and nystagmus on the opposite side. It becomes impossible to stand and, of course, to walk.

However, in a few days, the symptoms weaken and within a few weeks everything returns to normal. The healthy vestibule ensures recuperation (RUTTIN's compensation).

Bilateral labyrinthectomy induces much more severe disorders : complete ataxia and complete loss of myogenic tonus. But again, vision and myoarthrokinesthesic proprioceptors gradually bring a slow improvement and walking becomes again possible. However, we should remember that the animal remains definitely incapable of compensating for rapid loss of equilibrium -on an oscillating board for example- and if it is immersed in water, therefore also deprived of its deep kinesthesic sensations, it completely loses its equilibrium, whirls on its own axis and drowns.

What happens if only the myo-arthro-kinesthesic afferents are suppressed ?

It is difficult to obtain this suppression experimentally but there is one affection which induces this suppression : tabes which leads to sclerosis of the sensitive posterior columns of the spinal cord (by posterior radiculitis). This condition induces locomotive ataxia, a jerky walk and bad coordination. Even the standing or sitting position is disturbed. However, it is possible to maintain a certain equilibrium.

Claude BERNARD and SHERRINGTON have reproduced this syndrome in the animal by severing the posterior roots and the posterior columns of the spinal cord. The animal partly recovers from its locomotive disturbances.

What are the effects of the exclusion of visual afferences ?

It is obvious that they play a major role since vision gives immediate information about our environment, about the position of the body in space, the distance between us and various objects, the posture of the various body segments, etc...

However, vision requires integrity of the visual cortical sensation, i.e. the integrity of the occipital cortex. It is no longer a reflex in the strict sense of the word.

Finally, the role of vision is not more critical than that of other afferents : the proof is that blind people can walk and even practise sports such as skiing which requires a good equilibrium.

The role of vision becomes especially important if there is a lesion in the other regulatory systems of equilibrium, as in the patient exhibiting labyrinthine or tabetic ataxia, for example.

In addition, researchers tried to know what role the NERVOUS CENTERS play in equilibration.

In fact, destruction or mutilation experiments have shown that there is not one center regulating tonus distribution and equilibrium : they have shown which centers generate the previously described reflexes.

In the decerebrate animal, a generalized hypertonia ensues : it is the classical stiffness following decerebration (by suppression of the cortical inhibitor effects and of the influences of the thalamic reticular substance).

To achieve good equilibrium, the cortex, the thalamus and the corpus striatum must, therefore, also be undamaged.

In the decerebellate animal the stiffness is less pronounced. The role of the cerebellum is, therefore, not very important for equilibration. In fact, it is only placed in derivation on certain nervous pathways of equilibrium.

Finally, as a conclusion to this study of equilibration physiology we can say that :

- equilibration can be understood as a tonic and phasic regulation of muscular reflex ;
- static equilibrium can be understood as the regulation of myogenic tonus distribution by mechanisms mostly controlled by proprioceptors ;
- dynamic equilibrium also requires corrective movements (phasic) controlled by vestibular and visual mechanisms.

Finally, although equilibrium is regulated by :

- vestibular,
- proprioceptive,
- visual,

reflexes, with normal muscular tonus as a basic condition, none of these systems is absolutely indispensable or totally predominant. To use a modern expression, none has the "leadership" of this function : it is too important to be controlled by one regulator. However, all regulators are necessary to maintain equilibrium.

2. PHYSIOPATHOLOGY OF EQUILIBRIUM IN FLIGHT.

So far, we have only described equilibrium maintained on the ground or during movements on the ground surface. What happens in the aircraft or in the spacecraft flying in weightlessness ?

We shall see how certain systems fail in such environments, especially the vestibular system, which even becomes dangerous as it gives erroneous information. Vision then becomes the critical source of information, and if it should fail during blind flight, it must be replaced by the flight instruments.

The vestibular system becomes so dangerous that a booklet published for pilots by the U.S. Naval Air Force presents it as the caricature of a gigantic hair topped by an otolith named "oto" and described as ennemy n° 1 -the "villain" to use the American term- which cannot be stopped from entering an aircraft but must definitely be kept off the control instruments.

What actually happens during flight ? The usual stimuli received on the ground disappear nearly completely : physical contact is limited to the aircraft itself. In addition, the aircraft flies without being influenced by gravity. The stimuli of equilibrium are greatly altered by the kinetic flight factors : accelerations, decelerations, rotations of all types, during which the centrifugal force increases or gravity decreases.

In flight, the vestibular system becomes incapable of controlling equilibrium without a visual reference on the ground. In addition, the vestibular mechanism creates labyrinthine illusory sensations resulting from aircraft movements.

If we analyze the components of equilibration in flight, vision seems to be the only one which is absolutely necessary.

For the student pilot who learns to fly without instruments, horizon is the essential reference point.

In the early days of aviation, it already seemed that the best pilots were incapable of flying without an environmental visual reference (for example at night, in clouds or in fog). It was then discovered that birds themselves do not fly under such conditions : actually if a pigeon is placed in a cloud or in fog or is dropped blindfolded from a aircraft, it immediately starts gliding towards the ground.

Deprived of his vision, the aircraft pilot becomes the victim of ILLUSORY SENSATIONS which can have very serious consequences :

What are the most frequent illusions during flight ?

1/ Sensation of turning in the opposite direction after a roll or a spin :

The study of this illusion gives the pilot the most undeniable and sometimes dramatic proof of the failure of his own sensations and of the necessity to rely on the instruments.

Its mechanism is derived from vestibular physiology : when an aircraft starts rolling towards the right, the endolymph inertia first stimulates the cupula of the right external canal. After several rolls, after several rotations, if the aircraft comes out of the roll, the endolymph, bu its inertia, stimulates the left cupula -as on BARANY's rotary chair. A left nystagmus ensues, associated with a rotary vertigo toward the left, a deviation of the indexes and a fall to the right. Thus the pilot coming out of a right roll has the illusory sensation that his aircraft starts rolling to the left (as is shown by electronystagmography after the chair stops in the dark), while in reality it flies in a horizontal and straight plane.

To correct this false start of left roll he pushes the joystick to the right and starts a new right roll. The danger of such a maneuver at low altitude is easy to imagine !

David A. MYERS (American Flight Surgeon) demonstrated this illusion to convince the A.F.B. pilots of the necessity of using IFR. He showed that a pilot seating in the dark on a rotary chair is incapable of saying precisely when the chair stops turning or in what sense it rotates, whereas he no longer makes a mistake if he can watch a ball and an illuminated turn indicator resting on his knees. Without the instruments, he is incapable of telling in what direction he turns, particularly if the acceleration is subliminar (less than $1^{\circ}/sec^2$) : the labyrinth does not "detect" the movement.

Now the link trainer shows the pilots the necessity of instrument flying.

2/ Sensation of inclination, of tilting :

A second group of labyrinthic illusions includes sensations of inclinaison or tilting felt by the pilot while his instruments indicate that he is flying in a horizontal plane.

These illusions are due to the fact that the vestibule is not capable of detecting small subliminar displacements (under the vestibular excitability threshold). For example, if during a blind flight the aircraft suddenly rolls toward the right (while the pilot's eyes are not fixed on the instruments) and then gradually, imperceptibly returns to the horizontal position, the pilot who is not aware of the fact that the aircraft has recovered its equilibrium, keeps the sensation to have moved toward the right. The drive to correct the position by pushing the joystick to the left is irresistible for a pilot with no training to instrument flying.

In the same manner, if the aircraft suddenly starts pitching on an angle of a few degrees forward or backward and then gradually, imperceptibly returns to the horizontal position, the pilot is aware of the former displacement but unaware of the latter and also wants to bring the aircraft up.

Some pilots say that they are particularly sensitive to these illusions of small tilting movements (called "leans" in the U.S.A.) when they touch down in blind flight using radionavigation signals.

3/ These illusions can be compared to illusions arising from non apparent or undetected aircraft motions : they are no longer a slow return to the normal flight position but the slow motion -with minimal, subliminar acceleration- of rotation, ascension, descent, or inclination, which occur and increase without the pilot being aware of them.

The pilot can also underestimate the angulation degree of a turn in a blind flight.

4/ CORIOLIS reaction. The strongest vertigo reaction fo the vestibular system during flight is CORIOLIS vertigo or a vestibular response to the CORIOLIS acceleration.

The movement inducing this stimulation occurs when the body rotates along with the aircraft and the head is placed outside of the rotation plane. Vertigo reaches its maximum when the head displacement relative to the rotation plane is 90°.

This phenomenon usually occurs during a roll (or a succession of consecutive spins) if the pilot or passenger suddenly moves his head up or down or sideways. The subject experiences a sudden loss of equilibrium which, for a few seconds prevents him from controlling the aircraft.

This type of CORIOLIS vertigo can be reproduced on a rotary chair, in darkness, if during rotation the subject's head is suddenly driven forward. The subject has the impression to be propelled out of the seat.

5/ Sensation of climbing in a turn. This is another example of common labyrinthine illusion in blind flying. A correct turn brings the axis of the centrifugal and gravity force into the same vertical plane of the aircraft. If there is no visual reference, the only sensation is that of the body "pressing a little harder on the seat". It is both a proprioceptive and an otolithic sensation. Usually, this sensation is felt while the aircraft is climbing and can therefore be erroneously interpreted as such.

6/ Sensation of descent at the end of a turn. Following the body weight increase applied to the seat during the turn, the pressure is released (when the centrifugal force disappears) and an illusion of descent is felt.

These few simple examples are sufficient to show that the vestibular system can potentially generate numerous and variable sensations during flight. Whereas otoliths have a relatively simple behavior, the semicircular canals can be stimulated individually or in groups, associating or not their action with that of the otoliths.

If one takes into consideration the displacements imposed to the aircraft by the air turbulence and potential sudden movements of the pilot's head, one can imagine that the sensory afferences of labyrinthic origin, which are numerous and contradictory and often disagree with the visual information, overlap and confront each other in consciousness, thus creating the illusion and making it impossible to evaluate exactly the aircraft movements.

The myo-arthro-kinesthesic sensations are sometimes also erroneously interpreted in blind flight, in spite of the old concept of "piloting with one's seat" of ancient pilots. This type of flying also generates illusory sensations.

Do our deep proprioceptive system and vestibular system which fail during aircraft flight give more precise sensory information during ASTRONAUTICAL FLIGHT ? Once the spacecraft is on orbit a new factor appears : WEIGHTLESSNESS which greatly disturbs our functions of equilibration.

Before manned flights, a great number of animal experiments have been carried out, so that the physiopathology of weightlessness is quite known. It can be briefly conclude from these experiments and manned spaceflights that : the myogenic tonus which is the basis of equilibrium on earth is seriously deteriorated in weightlessness. The unconscious and permanent contraction of the muscles which support the parts of the body against the effects of gravity suddenly disappears when entering weightlessness, thus allowing the parts of the body to be lefted upwards.

The eye, in particular, moves upward (YUGANOV has filmed this displacement in the rabbit). This phenomenon is the basis of a particular illusory sensation : the oculo-agravic illusion described by GERATHEWOHL and STALLING (in which the objects seem to move downwards) which disappears after a few seconds or a few minutes.

This muscle slackening is made worse by the OTOLITHIC DYSFUNCTION : under the effect of weightlessness the otolithic membrane "floats" in the endolymph (where it is in equilibrium only if there is a gravity of 1 G. This phenomenon leads to the disappearance or the deterioration of the bioelectric activity of the ciliated cells of the macula which partly regulate the myogenic tonus. This, in turn, leads to very pronounced muscular atony, motor incoordination, and spatial disorientation which cause "space sickness" with nausea in certain astronauts as TITOV, in particular, who felt these symptoms very strongly.

It has been said that the animal behaves in weightlessness as a labyrinthectomized animal, which can be accounted for by the failure of the utricular (otolithic) system.

However, previously labyrinthectomized animals which had time to develop a visual and kinesthetic compensation have, in weightlessness, a less confused behavior than normal animals. In any case, animals adapt more or less to these new conditions, using their vision and touching the surrounding objects.

However, in the case of deprivation or dysfunction of the otolithic sensory afferents, the semicircular canals function normally. This phenomenon has been demonstrated in 1963 by ROMAN, WARREN and GRAYBIEL who were respectively Flight Surgeons on the A.F.B. of Edwards (California), Brooks (Texas) and Pensacola (Florida). In man, describing Keplerian trajectories in a rotating aircraft submitted to weightlessness for 46 seconds the oculoscopic illusion and the rotary sensation were recorded. These authors have found no difference between the sensitivity of the semicircular canals at 0 G (weightlessness) and at 1 G under the same rotary flight conditions.

This result could be logically expected since, contrary to gravity, the inertial force persists during orbital flight : the endolymph pushes the cupula and stimulates the ampullar crests by its inertia. The mass does not play a role as it does in the functionning of the otolithic macula. It seems, therefore, incorrect to say that the animals or man are "delabyrinthed" in weightlessness ; they are only "demaculated" or "desutriculated", but these terms are not very elegant, so we rather continue saying that they are "PARTIALLY DELABYRINTHED".

We should remark that this partial delabyrinthization by utricular dysfunction in weightlessness -with the ensuing disorders- disappears when the astronaut lands on other planets, the moon first, with a gravity equal to 1/6 of the earth gravity. This gravity is enough to reduce the labyrinthic disorders and the ensuing disorientation phenomenon.

In any case, animals and man adapt after a while to the new environment owing to the visual, tactile and psychic compensations. The cerebral cortex actually plays an important role : the psychological profile of the individuals increases or reduces the experienced disturbances.

We should remember that the first time the American pilot of the rocket plane was exposed to weightlessness (for 2 minutes) and was asked to change directions he answered "for the time being I can't do a thing", but later he could perfectly well maneuver his aircraft.

We have seen in magnificent films, the Russian LEONOV and the American WHITE (the "space walkers") leave their capsule, maneuver and "work" in the spatial vacuum after a short period of adaptation. However, physical fatigue is also felt rapidly as the walk in space of the astronaut CERNAN showed.

For aircraft pilots, vestibular adaptation and disadaption also exist, which we studied with P. ROBERT. It is called "psycho-labyrinthic syndrome" as it is closely related to the cerebral cortex and psychic equilibrium.

The adaptation of man to the flight conditions must be acquired by training : flight training, training on the ground, also in link-trainers and flight simulators which become more and more important for training astronauts who must learn how to face all the possible situations which can arise during spaceflight. The partial failure of the Atlas-Agena space rendez-vous could have resulted in a tragic catastrophy if it had not been for the cool-headed attitude of both astronauts acquired in the space flight simulator, who made the

necessary manoeuvers to stabilize and separate the two spacecraft caught in dangerous spins.

CONCLUSIONS.

As a conclusion, we should remember that some of the systems which usually maintain our equilibrium, such as :

- the system of myo-arthro-kinesthetic proprioceptors,
- the vestibular system with the ampullar crests and the utricular maculas,

become useless or even dangerous during flight.

Vision plays a major role in the maintenance of equilibrium in aviation or space-flight. It allows man to move in the desired direction, to ensure his equilibrium inside the craft and to maintain it, under adequate operation and equilibrium of the craft it-self by keeping sight of the panel instruments.

Also, the exteroceptive stimulations (of the skin receptors) which play a secondary role in equilibration on earth play an important role in weightlessness, and correct, in association with vision, the labyrinthine and muscular failures.

Finally, if the integrity of the central nervous system and of the cortex is a very important factor for equilibrium regulation on the ground, the role of the psychic nervous system is more important still. It is indispensable if man is to adapt to new conditions of equilibrium in a new environment.

What BERGSON said before the first aircraft flights "the bird stretches its wings and flies... man burns his wings and kills himself, but he will learn to fly as he has learnt so many other things, because he knows what he is doing" remains true for the space-flight era.

NEW ASPECTS OF BAROTRAUMA IN O.R.L.

by

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1. REVIEW OF PHYSICS AND CONDITIONS FOR ATMOSPHERIC PRESSURE VARIATIONS.

The layer of air surrounding the earth puts a pressure on the ground and, consequently on our body. This pressure equals 1 kg/cm^2 or 760 mm Hg at sea level.

It slightly varies, depending on the weather conditions, but above all as a function of the altitude above sea level.

- Close to the ground, air is denser because it supports all the air above it,
- But at 18,000 ft above sea level, the pressure is about 380 mm Hg, i.e. it is reduced by half,
- at 28,000 ft, the pressure is about 248 mm Hg : it is reduced by 2/3,
- at 33,000 ft, it is about 196 mm Hg : it is reduced by 3/4,
- at 60,000 ft, the pressure is only of 50 mm Hg, so that it is possible to plot this pressure variation as a function of altitude. An asymptotic curve is thus obtained.

Such a curve shows that at high altitude the pressure drop is very gradual :

- in the stratosphere, it equals a few mm Hg,
- in the thermosphere (from 60 to 300 miles), pressure is lower than one dyne/cm^2,
  It equals 0.23 mm Hg at 200,000 ft,
- above 300 miles, in the exosphere, there is practically no air pressure at all : there are only a few molecules/cm^3. True space begins there, more exactly above 600 miles.

In other words, no man had really entered space before Apollo VIII. Its inferior limit was only reached by the Soviet dogs launched in 1966.

As far as deep sea diving is concerned, one must know that pressure increases under the sea level. The figures are very high for immersion. Pressure roughly increases by 1 kg/cm^2, i.e. 1 atmosphere every 33 ft. Barotrauma is more important for divers of the "world of silence" than for pilots.

<u>What are the conditions for atmospheric pressure variations in man</u> ?

In the navy or during submarine incursions :

- during deep sea diving (free or with self-operated diving-suit), pressure increases.
- it decreases while coming back up to the surface.

In conventional submarines, personnel are exposed to the effects of atmospheric hypopressure when the snorkel valve is functioning (a type of valve preventing water from entering the submarine navigating with a perioscope.

When the Snorkel valve closes, the Diesel engines draw in the inside air, thus causing a slow pressure drop. When it opens again to release the air, the pressure immediately increases in the submarine. This sudden overpressure reaches about 220 to 250 g/cm^2. At that time, overpressure effects can cause trauma.

In aviation, atmospheric pressure changes depend on the climbing or descending speed of the aircraft. Variations occur quickly in high performance aircraft and even faster with rockets which shoot up at a speed of 8 km/sec to be placed on orbit and of 11 km/sec to be freed from earth attraction. However, barotrauma, can be avoided by pressurization.

Finally, it is necessary to know that a particularly rapid air trauma, the explosive decompression trauma, can be caused in aviation by the use of pressurized cabins. If the cockpit wall or window breaks open, or if the pressurization system fails at high altitude, the pressure drops quickly, within a fraction of a second.

The cabin altitude can, for example, drop from 6,000 feet (nominal altitude) to 4,000 feet (real altitude). The decompression time is a function of the size of the pressurized cabin and of the dimensions of the breach in the window or cockpit. The smaller the cabin is, the more rapid and traumatizing the decompression effects are.

In order to understand the effects of these changes on man in atmospheric pressure,

one must know the physical laws of gas expansion.

The most important of these laws is Boyle's law (also known as Mariotte's law) which is expressed by the following equation :

$$P = \frac{\text{constant}}{V} \quad \text{or} \quad P \times V = \text{constant}$$

and Boyle-Mariotte-Gay Lussac's law which takes into account the gas temperature :

$$P \times V = R \times T$$

Where T is the temperature and R a constant.

These laws state that :

"At a constant temperature, the pressure of a mass of gas is inversely proportional to the gas volume" or "the volume of a gas is inversely proportional to the pressure of its environment".

If the pressure drops, as it does during the climbing phase of a flight, the gas volume increases. Inversely, if the pressure increases, as it does during the descending phase, the gas volume decreases.

This can be very clearly demonstrated in a decompression chamber, using the traditional empty soda bottle, with its neck closed by a soft rubber balloon : the balloon blows up during ascent and gradually returns to its original volume during descent.

2. PHYSIOLOGY OF PRESSURE CHANGES IN THE EAR.

This physiology essentially depends on that of the eustachian tube, as it is the latter which ensures ear ventilation and acts as a valve, equilizing pressure on either side of the tympanic membrane. Equal pressure is indispensable for normal hearing.

1/ Physiology of tube muscles

The peritubar muscles act in synergy for 3 functions :

- deglutition
- phonation
- ventilation of the tympanic cavity.

The tensor palati muscle, with its fibers inserted on the fibrous wall of the isthmic portion of the eustachian tube opens the tube lumen.

It is an isthmic muscle which also sub-tends the soft palate. It is a typical tubar muscle. It is inspiratory, acts on the fibrous wall, the only wall which is not wrapped in cartilage. It opens the tube lumen ant the air penetrates into the middle ear.

The levator palati muscle first acts on the posterior ridge of the cartilage of the tubar opening. It is an ostial muscle. It simultaneously puts the velum palati in a horizontal position ; it is also a dilator muscle.

An important point of this tubar physiology is also the action of the tensor tympani muscle, emphasized.

A sufficiently strong physiological or voluntary muscular contraction of the levator and tensor palati determines a synergy of the contraction of the tensor palati muscle and of the tensor tympani muscle, which draws the ear-drum toward the internal wall of the tympanic cavity.

Both muscles receive the same innervation via the motor root of the trigeminal nerve.

This adduction of the ear drum isolates the attic (housing of the ossicles) from the remaining tympanic cavity, thus protecting the ossicular system. The adduction of the tympanic membrane is rapidly followed, as soon as the muscle contraction stops, by a quick movement of the membrane returning to its place. This movement is only due to the membrane's own elasticity.

The tympanic adduction has expelled a little air from the cavity, especially from its anterior portion. When it suddenly snaps back, it draws in through the tube, which is still open, a volume of air at least equal to that which came out of the cavity. This volume is sufficient to maintain in the middle ear the slight overpressure which is normally there. It is therefore not surprising that a certain pressure is necessary to let the air fill the tube when the nasopharingeal end of the tube opens. The sudden abduction of the ear drum helps drawing this air toward the cavity.

There is a relationship of interdependance between the muscles of the soft palate, an those of the tube and malleus. This interdependance actively regulates the tympanic movements and the tubal permeability.

2/ Mechanism of the eustachian tube

Normally, the eustachian tube is closed at rest, at least its pharyngeal segment (this is due to its anatomic conformation and also to the wetness of its mucous membrane which keeps its walls in close contact). It only opens during movements which involve contraction of the tube muscles : yawning, sneezing, shouting and, especially, deglutition. It is influenced neither by soft breathing nor by speech.

The eustachian tube could be roughly compared to a rigid wooden tube, for example, connected to a fine hose of soft rubber. (The wooden tube represents the rigid osseous tube and the rubber piece the pharyngeal tube). It is easy to blow air with the mouth in the direction wooden tube rubber hose, but it is harldy possible to suck air the other way.

This is what happens in the physiological reality : during the climbing phase, air is "blown" in the direction ear nasopharynx and during descent, air must be drawn in the reverse direction : it can only be drawn if the rubber hose, i.e. the pharyngeal tube, is kept wide open.

Given this particular tube structure, air is more easily expelled from the middle ear than admitted from the nasopharynx.

During ascent (aircraft or submarine), there should not be any problem : according to Boyle's law, the air pressure drops and the volume increases in the inner ear. The air can escape by one opening only : the eustachian tube. It is easily expelled.

During descent, the pressure increases and the volume is reduced. The middle ear must draw in air contained in the nasopharynx. This is more difficult. Physiological deglutition opens the pharyngeal opening of the eustachian tube. This deglutition occurs approximately every 60 sec. in wakefulness, and every 5-7 min during sleep, thus allowing for pressure equalization between middle ear and nasopharynx.

In an aircraft, the changes in atmospheric pressure during flight depend on the climbing or descending speed : in order that a pressure change can be felt in man's ear, it must be 3 to 5 mm Hg, i.e. a difference of 100 to 180 feet. At this stage, one has the feeling of a full ear and otoscopic examination shows that the tympanic membrane slightly bulges out.

As the aircraft continues climbing, the bulging phenomenon and the sensation of full ear become more pronounced as a result of the pressure drop. When the pressure reaches 15 mm Hg (at about 500 feet) the subject feels that his ear pops : the ear drum returns to its normal position, the full feeling disappears, hearing improves : the tympanic overpressure blows open the eustachian tube.

During further climbing, this cycle is repeated : successive popping sensations are felt at pressure change intervals of about 11.4 mm Hg, i.e. every 435 feet.

Although the curve plotting atmospheric pressure versus altitude is not a straight line, the eustachian tube opens at regular intervals (except for the 1st one).

However, if a differential pressure of 11.4 mm Hg is required at low altitude to open the eustachian tube, a pressure change of 3.5 mm Hg is enough at 40,000 feet to produce the same result.

Why is it so ? Probably because air at high altitude is less dense and passes more easily through the tube.

These numbers are averages derived from tests carried out on normal individuals. However, there are major individual variations, from 5 to 30 mm Hg, i.e., a factor of 1 to 6 at sea level.

During descent, when the outside atmospheric pressure increases, the pressure in the middle ear drops instead of increasing and the effect is different : the eustachian tube remains closed if the tube muscles do not work. In a decompression chamber, certain subjects have withstood a negative pressure of minus 470 mm Hg in the ear.

However, if the negative pressure in the middle ear reaches 90-100 mm Hg, it is usually impossible, even by muscular action, to open the membranous tube which remains collapsed. It is then necessary to increase the altitude (in aircraft or decompression chamber) in order that the difference is brought back to less than 80 mm Hg so that deglutition opens the eustachian tube.

3/ In addition to the muscles and to the role of pressure equalizing, the eustachian tube protects the middle ear.

The shape of the eustachian tube (hour-glass, elbow-shaped isthmus and flattened pharyngeal segment) gives the tympanic cavity a relative independance which protects it from the sudden physiological changes in the pharyngeal pressure. Actually, if the tube remained permanently wide open, hearing would be seriously impaired ; the inspiratory decompression and expiratory overpressure, the deglutition and chewing noises would be

transmitted to the ear and disturb hearing (which sometimes happens in certain syndromes where the tube remains wide open).

4/ The changes in atmospheric pressure are transmitted, through the eustachian tube, to the inner ear itself.

It is actually shown that a change in the pressure of the middle ear affects the cochlear labyrinth and even the intracranial pressure.

In 1962, AUBRY, PIALOUX and BURGEAT have shown this in the study of the cochlear microphonic potentials as a function of the pressure changes inside the middle ear in the gerbil and the guinea pig.

They experimented on 27 animals. An electrode was introduced into the scala tympani of the cochlea of each animal (a copper microelectrode of 50 microns) according to the technique of DAVIS (the indifferent electrode is placed in the cervical area).

This first device permits registration of the cochlear rest potential on a cathodic oscillograph.

A second device is designed to achieve a sound stimulation of 380 and 4,880 Hz. On the one hand, by aerial transmission in the external auditory tube of the animal, on the other hand, by osseous transmission using a 190 sound level tuning fork.

With these stimulations it is possible to record, with a cathodic oscillometer, the cochlear microphonic potential or cochlear action potential (different from the nervous action potential per se which is generated further down in the cochlear nerve) in the shape of waves at more or less close intervals which reproduce the phase of acoustic sound waves.

A third device is designed to reproduce a hyperpressure in the middle ear, using a small 2 mm diameter tube, fixed leak-proof in the middle ear of the animal and connected to a syringe (a double piston movement allows for variation of the tympanic pressure) and to a water pressure gauge which measures these pressures.

These experiments give interesting results :

a) In animals with intact ossicular system :

. In decompression (which corresponds to descent, where a gradual decrease in the cochlear microphonic response is observed which disappears at around 6 cm of water, then reappears, without returning to normal if decompression is increased, but which a 180° change in phase),

. in overpressure (which corresponds to the climbing flight phase),

one observes :

. a slight decrease in the amplitude of the microphonic potential for low pitch sounds,

. no change for high pitch sounds.

b) In animals with a destroyed ossicular system (rupture) :

In this case, no change in the cochlear microphonic potentials occurs, neither in overpressure, nor in decompression and neither by aerial nor by osseous transmission (except, of course, if the decompression brings the malleus back in contact with the stapes, in which case the cochlear microphone increases because of better transmission).

From these interesting results it should be remembered that :

1. A change in pressure inside the cavity very easily influences the amplitude of the cochlear microphonic potentials. The middle ear can be compared to a very sensitive pressure gauge since variations of less than 1 cm of water have a noticeable effect on the cochlear potentials.

2. The negative pressures play an important role, whereas the positive pressures have a minor influence.

3. The maximum effect is obtained in the aerial transmission for the low pitch sound, where for a decompression equal to 6 cm of water, one obtains total disappearance of the microphonic potential.

4. The phase modification observed at 380 Hz confirms the role -showed by Wever- of the ossicles in dephasing between the oval window and the round window, as well as the absence of effect after permanent rupture of the ossicular system.

These facts certainly seem to indicate that the changes in the mobility and position of ossicles are due to disorders caused by a disequilibrium in the pressures on either

side of the tympanic membrane.

5. Finally, although they are less reduced than the cochlear microphonic potentials obtained by aerial transmission, the cochlear microphonic potentials obtained by osseous transmission are also reduced when the pressure changes.

These facts lead us to consider the role played by the ossicular system in the mechanism of osseous conduction as is confirmed by the amplitude drop of the cochlear microphonic potentials obtained after persisting rupture of the ossicular system.

Do the atmospheric pressure changes in the middle ear affect the posterior labyrinth ?

This is a sure fact. Clinically, we know the fistula sign (nystagmus and vertigo induced by pressure of Siegle's otoscope in the external auditory tube. No experiment was carried out on this aspect, but we can assume that if the cochlear microphonic potentials are reduced, the vestibular action potentials are also reduced.

The cochlear damage caused by sudden air hyperpressure in the eustachian tube and the middle ear can be serious as in the case -reported by DEBAIN in 1965- of a sudden hearing loss following a sneezing spell. In 1972, we observed a case of sudden hearing loss and vertigo in a 60 years old woman, resulting from rapid decompression in the airliner in which she was flying. Several other cases have been observed since.

3. SINUS VENTILATION MECHANISM.

Boyle's law applies to the air cavities of the face as it does to the middle ear.

To understand what happens, we can imagine a soft walled sphere, for instance a closed rubber ball, and a stiff walled sphere, for instance, a glass container with an opening at its undermost point.

If they are gradually immersed together :

- at the surface, at atmospheric pressure, the air volume inside the rubber ball and the glass container are equal : 60 cu inches.

- at 33 feet, the pressure equals 2 atmospheres, the volume is reduced by half, the soft walled ball is reduced by half.

The glass container does not change but the air contents are reduced by half and water is drawn in.

The exact same phenomenon occurs when diving : water penetrates the sinus. When the aircraft descends, air which becomes more and more dense enters the sinus.

Let us suppose, now, that the opening of the glass ball is closed and that the same experiment is carried out at a pressure twice as high : the wall of the ball is under a pressure of 28.5 lb p.s.i. whereas the air contained inside is at a pressure of only 14.2. lb p.s.i. A discrepancy ensues between the inside and the outside, with a maximum effect on the ball opening.

In sinuses, this opening is the ostium : if it does not open, the inner decompression causes damage or mucous lesions.

The functional pattern of sinuses is the following :

- in the climbing phase, overpressure builds up in the sinuses because of lower atmospheric pressure. At a given time, the differential pressure is high enough to force open the ostium and expell some air out of the sinus ;

- in the descending phase, the air volume contracts in the sinus. Air is drawn in from the nasal cavity and travels in the reverse direction. However, if for any reason the ostium remains closed, a barotrauma ensues.

Anatomy and physiology show that the equilibration system of rigid walled sinuses is simpler than that of the ear with its soft wall and soft ventilation duct (eustachian tube). This explains why the disorders, related in aviation, to pressure changes are 20 times less frequent for sinuses than for the ear. With the exception, however, of the frontal sinuses which communicate with the nasal cavity by a 1.2 inch long canal and not by a simple ostium. This is why the frontal sinuses are 3 to 5 times more exposed than the other sinuses to disorders resulting from pressure changes.

Finally, Boyle's law reveals a critical fact : the greatest pressure and volume changes occur near the surface. It is, therefore, much more dangerous to go 3 feet under the surface than to go from 160 to 190 feet under water. In aviation, barotrauma is more dramatic at low altitude than at high altitude.

The mechanism of sinus ventilation during pressure changes is much simpler than that of the middle ear. It no longer depends on the synergic action of certain muscles, but only requires good operation of the ostium, i.e. permeability. In addition, the ostia of the anterior sinuses are clinically more easily accessible than the tubal ostium.

4. CLASSIC BAROTRAUMA

We will not discuss classic barotrauma as it is a well known phenomenon and does not raise problems as far as diagnosis or therapy are concerned.

The most frequent form of ear barotrauma is barotraumatic otitis, a middle ear otitis. The 5 stages of HAINES and HARRIS are still classical references. The pathogenesis is tube obstruction by temporary (common cold, allergy) or chronic dysfunction.

There are also forms of chronic barotraumatic otitis.

Sinus barotrauma is usually barotraumatic sinusitis. This condition generally affects flying personnel with a sinus history and insufficient permeability of sinusal ostia (of the naso-frontal canal in particular). Frontal sinusitis is the most frequent sinus condition.

5. NEW ASPECTS OF BAROTRAUMA : COCHLEO-VESTIBULAR BAROTRAUMA

Barotraumas are more and more frequent. We have realized, for several years, that they do not only affect the middle ear.

This new chapter in the study of otologic barotrauma reviews the inner ear barotraumas also called cochleo-vestibular barotraumas.

First : forms of barotraumas associated with sudden hearing loss (sensori-neural deafness). We observed several cases. The general pattern -usually affecting divers- is the following : under water, they suddenly feel vertigo and come up to the surface where they realize that one ear is completely deaf. Sometimes both ears are affected, to different degrees.

These symptoms can be experienced by the pilot or the passengers of a pressurized aircraft in case of rapid or explosive decompression. Vertigo usually disappears but hearing loss persists in spite of a partial regression which sometimes occurs in the following weeks. This is an acute type of accident.

There are also chronic (or progressive) forms of cochleo-vestibular barotraumas. The first cases were reported by BOZZI who described progressive perceptive hypoacousis in divers, associated with vestibular disorders. The audiometric and vestibular tests performed on divers showed:

- more or less pronounced hypoacousis of neurosensory type, associated with disorders predominantly affecting high-pitched sounds, as it is the case for professional hearing losses due to sound trauma ;

- a vestibular hyporeflexia.

We observed several cases in professional divers, among whom one case in a 30 years old man who did not disclose his activity for fear of being declared unfit. We observed in this subject the gradual and slow progression of a chochleo-vestibular syndrome. All diagnoses had been considered (neurinoma of the vestibular nerve, multiple sclerosis, etc.) and examinations were performed. Lumbar punctures frightened him less than confessing his passion for diving. However, he finally told he was a diver. This case was a typical case of the chronic cochleo-vestibular hearing loss syndrome caused by barotrauma.

What pathogenic hypotheses can we consider in order to explain such syndromes ?

In the case of chronic affections, BOZZI first evoked the enormous hydrostatic pressure which could compress the peripheral circulation on the diver's body surface, thus leading to an abnormal filling of the internal vessels, including the internal auditory artery. The arterial hypertension could then be the cause of hypertension of the labyrintine fluids.

BOZZI also mentioned the action of sudden changes in the water temperature at different depths, which induce a real thermal and vasomotor trauma.

A more interesting hypothesis is that of nitrogen microemboly in the vessels of the vascular stria of the cochlear canal, with infraction of the neuroepithelium or release of nitrogen in the endolymph which causes vertigo and hearing loss.

This hypothesis of gas microemboly in the cochlear and vestibular arteries is quite tempting.

It can be related in aviation medicine to the physiopatholgoy of articular pains at high altitude (bends), chest pains and respiratory trouble (chokes), and cutaneous parasthesia (creeps) which can affect pilots, and are also due to micro-airembolisms.

Other authors have suggested the possibility of a sprain in the stapedovestibular joint which could cause tension disorders in the labyrinthine fluids. The role of major persisting vascular spasms has also been considered, probably with a hint of truth.

The role of sprains or stapedial "piston stroke" effects in the inner ear has never been confirmed in normal subjects, but CAUSSE has observed by surgery the displacement of Shea's teflon prothesis in subjects operated for otosclerosis after sufflering violent barotraumas, especially crossing of the sound barrier at low altitude (sonic boom). One of these patients had suffered such an intense vertigo that he had fallen into the lake where he was fishing.

Finally, the last and maybe most interesting pathogenic case has been observed by Victor GOODHILL in Los Angeles. It is the most interesting from the standpoint that it can be cured by surgery : it is the case of sudden neurosensory hearing loss due to labyrinthine membrane rupture. He first observed, in 1971, ruptures in the membrane of the round window or in the ligaments of the oval window which cause a perilymph fistula in the middle ear.

In 1976, he performed tympanotomy for 59 cases of sudden hearing loss among which he observed 12 cases with no lesion but 47 cases with perilymph fistula including :

4 fistulas in the isolated round window,
24 fistulas in the isolated oval window,
19 fistulas in both windows.

(In the 12 cases without apparent lesion, there may be a rupture of the intra-cochlear membrane).

The etiology of the rupture is hyperpressure of the cephalopinal fluid (CSF) in the case of an "explosive" route and hyper-pressure of air in the case of an "implosive" route.

The implosive route is a barotrauma caused by a sudden pressure increase in the middle ear (Valsalva's maneuver, blowing one's nose violently, rapid decompression. Hyperpressure comes from the tube and the tympanic cavity. It causes a rupture of the round or oval window or both.

The "explosive" route is the sudden hyperpressure of the CSF due to barotrauma or to simple physical effort. Hyperpressure is transmitted to the inner ear by the cochlear duct and can lead to various lesions, including window rupture by applying a pressure contrary to that of the implosive route. In both cases, a slight vertigo ensues, associated with sudden hearing loss and tinnitus.

In the case of the perilymph fistulas observed by *GOODHILL*, physical exercise or barotrauma were obvious in certain cases, imprecise in others. Labyrinthine window ruptures were sometimes, but not always, associated with vertigo in deep sea divers, with no connection with signs of nitrogen gas embolus and some windows were ruptured during air flights. In other cases, hearing loss appeared suddenly, following physical exercise such as lifting heavy loads or unusual exercise. I observed such a case in a rugby player who suddenly became deaf after half-volleying the ball.

What is especially interesting in these cases of sudden hearing loss due to the rupture of labyrinthine windows is that they must be rapidly operated on, if hearing is not recovered by medical treatment. Surgery is not only performed for transmission hearing loss. Some neurosensory losses must be treated by tympanotomy. This leads us to discuss the new aspects of ear barotrauma treatment.

6. NEW ASPECTS OF TREATMENT OF BAROTRAUMA

1/ Middle ear barotrauma

The general use of the binocular surgical microscope allows for better diagnosis and therapy : aseptic puncture with a fine needle, possible paracentesis, Sheppard's drain (Grommet) etc...

2/ Cochlear and vestibular barotrauma : medical emergency

From a therapeutic standpoint, what matters is the treatment of hearing loss, as vertigo disappears spontaneously. Even is a mild form, hearing loss is a medical emergency. The patient must be immediately put under medical care and be hospitalized if there is no improvement after 4 to 5 days.

The following action should be taken :

- the patient should rest in a quiet environment and be given tranquillizers and neuroleptic drugs if necessary,

- the active treatment is mostly a vascular treatment : vaso-dilatators and blood thinners associated with cell oxygenators.

If hearing loss is moderate, oral treatment can be sufficient. However, if it is severe or if the patient does not recover hearing after a few days of oral treatment, he must be hospitalized to receive a more active vascular treatment with i.v. injections or

continuous perfusion (hyperbaric oxygen has been successfully used when the equipment was available, but his treatment involves some risks). Vitamin therapy with B_1, B_6 and B_{12} vitamins and xylocain infiltration into the cervical sympathic system can be associated with the vascular treatment.

In after 8 days of treatment no result is obtained, surgical exploration of the middle ear by tympanotomy is necessary. The surgeon must search under enlargements of 16 x and 25 x the signs of perilymph fistula in the labyrinthine windows. A real hole can rarely be observed at the center or on the periphery of the round window. All fistulas must be obturated by a perichondral or vein graft (auto-graft) kept in place by gelfoam. The tympanomeatal flap is put back in place. The patient is kept in bed, immobile, for 6 days, with his head tilted to 30° for 48 hrs.

Out of 47 operations, GOODHILL obtained 25 % audiometric gains of more than 30 dB and 18.75 % small audiometric gains. In nearly 60 % of the cases there was no improvement.

However, medical treatment must be continued as it can be a case of intra-cochlear membrane rupture (REISSNER's membrane, basilar membrane, etc.). This treatment will accelerate healing of intra-cochlear lesions.

NOSE PATHOLOGY OF FLYING PERSONNEL

by

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Examination of the nasal cavity not only means study of its permeability or checking for acute or chronic infection but also indirectly, checking whether or not the middle ear (ear drum and ossicular apparatus functions properly.

The eustachian tube which connects these two cavities through the post nasal space plays a definite role in the physio-pathology of the nose-sinus complex.

Examination of the nasal cavity and of its adjoining cavities, of the sinuses and study of the functionning of the auditory tube are very important for flying personnel. We first consider the practical conditions for such an examination, as carried out in the Centre Principal d'Expertise Médicale du Personnel Navigant (C.P.E.M.P.N.) in Paris, and then some of the concrete problems confronting the specialist of nose or tube pathology in flying personnel.

1. PRACTICAL EXAMINATION OF NASAL CAVITY, SINUSES AND EUSTACHIAN TUBE.

1/ Anterior rhinoscopy should permit simple examination of the anterior 2/3 of the nasal cavity. This examination can be made without decongestion, or, better still, after decongestion with gauze impregnated with a vaso-constrictor.

The physician can use the following procedure :

- assess the region of the middle meatus which is the physiological crossroad of the nasal cavity, collecting discharge from the various facial anterior sinuses.

- check, in a simple but conscientious manner the emptiness and the permeability of the air duct (inferior and middle meatus).

Most often, this simple and rapid examination is enough to check out this last function ; however, it is sometimes impossible to see the posterior wall of the post nasal space, which is hidden either by a posterior deviation of the nasal septum or by a pathological mass.

2/ Posterior rhinoscopy, the only examination which permits :

- observation of the choana
- evaluation of the size of the posterior ends of the turbinates
- checking the post nasal space and the pharyngeal openings of the auditory tube.

3/ We do not systematically take sinus X-rays.

Only if sympomatology indicates the need, we ask that 3 X-rays be taken :

- occipito-frontal view) maxillary and frontal sinus
- occipito mental view)
- submento vertical view ethnoidal and sphenoidal sinuses

completed or not by tomographic sections.

4/ Eustachian tube : the pressure equilizing function of the tube can be indirectly evaluated by :

- the aspect and mobility of the tympanic membrane (Siegle's otoscope, Valsalva's maneuver)

- a test using Itard's catheter

- an audiometric study.

Actually, when there is a doubt about tube permeability, we carry out two tests :

- simulated climbing in a decompression chamber (preceeded and followed by otoscopic and audiometric examinations),

- and also, currently, an impedancemetric examination of the middle ear.

This simple and rapid examination will probably become as important as the audiometric examination. Testing the impedance of the middle ear provides information about the mobility of the tympanic membrane and of the ossicular system, and about tube permeability.

After all these examinations are completed, which problems can be possibly encountered ?

2. SOME CONCRETE PROBLEMS.

1/ Deviation of the nasal septum

The nasal septum is rarely as vertical as nature wishes it, especially in the white race. For a long time, any deviation of the nasal septum, even minimal, was considered a factor of unfitness and a cause for surgery when found in flying personnel.

This solution often induced further problems such as post-surgical perforation and atrophic rhinitis. In addition, it often did not significantly improve nasal permeability.

Our experience has showed us that nasal impermeability was more often induced by hypertrophic or allergic mucous tissue than by cartilage deviation.

Our present attitude is therefore much more discriminating : major deviations which cause total or subtotal obstruction of the nasal cavity obviously remain incompatible with flying activities. We are more lenient towards other deviations, i.e. we first recommend medical therapy, maybe even cauterization of the turbinates.

Impedancemetric examination will permit systematic evaluation of the effect on the tube functioning.

2/ Acute nasal or nasal-sinusal infections

Such infections must systematically lead to temporary unfitness.

They are indeed the cause of sinus barotrauma (now less frequent than in the past due to cabin pressurization) and especially of otitic barotrauma, either acute (as revealed by conventional symptomatology) or sub-acute (therefore neglected and leading to deafness). Symptomatology will determine how long the patient remains unfit.

We can never insist too much on the educational role that the physician responsible for the medical surveillance of the flying personnel must play to avoid abuse in the use of drugs prescribed for nasal pathology : the more a substance absorbed by the nasal passages acts actively on permeability, the more it acts adversely on the mucous membranes. It should therefore be used as little as possible : vaso-constrictors will nerver be prescribed for a treatment exceeding a maximum of 8 to 10 days. Sulfur products can, however, be extensively recommended.

3/ Chronic nasal or nasal-sinus affections

a. Due to infection :

Chronic nasal or nasal-sinus affections due to infection make the patient unfit until he is cured.

- If it is proved that a maxillary sinusitis is caused by dental problems, the patient can undergo a medical-surgical treatment which will then permit him to resume his flying activities.

- If the affection is purely infectious, treatment becomes more uncertain. Most often, the maxillary sinus is not the only center of infection. In most cases, we declare unfit subjects who show this type of affection at the admission visit.

At the time of the check-up visit, the temporary unfitness depends on symptomatology and it will be necessary to make use of all the resources offered by medical, surgical and termal therapy for these subjects if one wishes to avoid the nasal sinus infection extending to the eustachian tube and to the ear.

b. Due to allergy :

Nasal or nasal-sinus allergies are apparently becoming more and more frequent. It raises problems which are all the more complex as they often develop on particular "grounds" (asthma, headaches, ulcers, etc...) and affect different patients to various degrees.

Basically, our attitude is the following :

- periodic allergic rhinitis (hay fever) : temporary unfitness,
- a periodic allergic rhinitis : we recommend specific desensitization. The subject stops working during the periods of superinfection,
- nasal or nasal sinus polyposis :
  - . at admission : permanent unfitness
  - . at check-up visit : temporary unfitness, polypectomy, then desensitization and, possibly, spa therapy.

We have purposely limited our discourse to these few affections which are by no means representative of the total picture of nasal or nasal sinus pathology.

Actually, it should be noted that the ear-nasal cavity-sinus interrelation which is already very close in all individuals is even more pronounced in flying personnel exposed in their work to more or less rapid and severe pressure changes : the nose-sinus examination is always followed by otoscopic and audiometry examinations.

The decision to declare the subject fit or unfit can only be made after completion of all these examinations.

PRACTICAL PROBLEMS RAISED

BY OTO-RHINO-LARYNGOLOGY STANDARDS

by

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We review in this paper a number of concrete problems which can confront the expert when he applies the imposed standards both at the admission and check-up visits.

We will especially study otoscopic and cochlear problems.

But first, it is important to know some of the principles which guide the specialist in his examination.

The purpose of this examination is :

- Selection and medical surveillance of "high risk" personnel, in order to insure :

  . safety of people on board the aircraft and also
  . safety of the population on the ground.

- The flying personnel cost a lot to the Government : the training of an operationnal fighter pilot costs in France 15 million francs ; the formation of a Mirage F 1 pilot costs 30 million francs. These financial considerations should not be neglected and this is why even though it is imperative to be very severe at the admission visit, a certain tolerance is necessary at the check-up visits, as long as flight safety is not threatened.

Finally, let us recall that these standards vary as a function of the operations on board the aircraft.

For otorhinolaryngology, these standards require :

Perfect hearing, which implies not only anatomical and functional integrity of the whole ear (outer, middle and inner ear) but also of the nose - auditory tube complex.

Tubal dysfunction has more adverse effects on the cochlear function of flying personnel.

Pratically, the nose-throat and ear examination includes :

1°) Clinical examinations :

. systematic examinations :

- otoscopy (appearance and mobility of the tympanic membrane)
- anterior rhinoscopy
- oto-pharyngeal examination

. special examinations :

- microscopic examination
- posterior rhinoscopy
- X-rays

2°) Functional examinations :

- speech audiometry is no longer used ;

- systematic pure tone audiometry, the essential examination, will be performed both at the admission and check-up visits. (In this case, it may be useful to perform speech audiometry, both under silent and noisy conditions in order to test not the physiological conditions of the ear, but rather its reliability for social communication (flight safety) ;

- finally, a more recent examination which is becoming more and more important : IMPEDANCE AUDIOMETRY, which permits testing the functional value of the middle ear and the functioning of the Eustachian tube.

* Centre Principal d'Expertise Médicale du Personnel Navigant

CONCRETE PROBLEMS

1/ During clinical examination :

a) Acute infection of the outer or middle ear must lead to temporary unfitness, the duration of which will depend on clinical and functional symptoms.

b) Chronic middle ear infections :

. At the admission visit : any chronic otorrhea, whether tubal or antro-attical must lead to permanent unfitness.

. At the check-up visit : the doctor's attitude must be as discriminating as possible, taking into account the results of para-clinical examinations, i.e. audiometry and X-rays.

It is always advisable to declare the subject temporarily unfit in order to prescribe a therapeutic treatment.

The subject can resume flying only if there is no vital or functional risk and under the condition that the cochlear function is compatible with flying safety.

c) Dry tympanic perforation :

At the admission visit : the subject is declared permanently unfit as there is a definite risk of superinfection.

At the check-up visit : it is a special case, to be handled according to the results of clinical, X-rays and audiometric examinations.

d) Scarred tympanic membranes and sequelae of surgery on the middle ear :

In these cases it is also necessary to establish a complete clinical and paraclinical check-up in order to make sure that no infectious process is taking place and that the cochlear function is correct.

2/ During the study of the cochlear function :

a) Transmission deafness with closed ear drum :

tympanosclerosis) at admission lead to permanent unfitness even if cochlear
and) function is still satisfactory. In the first case flying will
otospongiosis) cause repetitive barotraumas, in the second case the condition
) always leads to deafness.

However, when these conditions are discovered at the check-up visit the subject can be considered as remaining fit for at least a few years ; actually as far as hearing is concerned, they will not be bothered for many years as they use their head sets as hearing aids.

In the case of otospongiosis, the subject is declared permanently unfit at the time of surgical treatment : actually, although surgery permits regaining excellent hearing for speech frequencies, it sensitizes the ear to sound trauma, thus encouraging secondary deafness of inner ear type.

b) Perceptive deafness :

- whether unilateral or bilateral, and whatever its cause may be, such deafness is an eliminatory condition at the admission examination.

- control visit : perceptive deafness is practically unavoidable for flying personnel after a certain number of hours. It is detected by pure tone audiometry but speech audiometry allows us to make a decision.

This examination will first be carried out in silence, hearing with both ears, then with a head set and finally in noise.

When the examination is satisfactory, i.e. when intelligibility remains adequate, the subject can remain active.

However, medical surveillance will have to be reinforced as intelligibility depends on cortical phenomena and is therefore relatively fragile.

c) Simulation :

This is a relatively rare phenomenon as subjects have a tendency to minimize rather than to maximize sympomatology.

The problem of simulation is most likely to arise when the subject is declared permanently unfit and claims compensation.

Comparison between the results of sound audiometry, speech audiometry and impedance audiometry most often permits uncovering voluntary contradictions.

In conclusion, let us remember that E.N.T. medical surveillance of flying personnel must take into account not only the problems raised by the individual, but also the requirements imposed by flight safety.

- ROUND TABLE -

(Written questions and answers)

1. QUESTIONS ASKED BY Dr BRENNAN to Prof. CHEVALERAUD.

Question 1 - Vision at low luminances.

Do you consider that the limited value of rod vision in military aviation warrants the adverse effects of red cockpit lighting ?

Answer -

Dr BRENNAN asks if red cockpit lighting is justified in spite of the problems it creates allowing for the limited vision of the rods.

This point has been discussed at an AGARD meeting a few years ago and two adverse tendancies came out. The first one in favor of White, the second one in favor of Red. The operational -therefore young- French crews answered a questionaire about the choice of illumination. It came out that they favor a very reduced illumination to maintain good outside vision during the critical flight phases (taking off and landing). Red illumination presents the same advantages and is therefore quite satisfactory.

During a cruise, the choice is not so clear.

But older crew members who have difficulties to read red illuminated instrument panels have divided opinions.

The French Air Force Medical Officers still favor Red.

Questions 2 - Glare in aviation

A) As the retina does not contain pain receptors, is the pain and disconfort produced by glare sources confined to the iris ?

Answer -

About glare related pain and discomfort, it is not a proven fact that it originates from the iris. Only protracted glares which induce spasms of the palpebral contraction may cause pain. Pain does not seem to be an important sign of glare.

However, the palpebral contraction may prove painful.

B) Does the French Air Force favor fixed filters, photochromic devices or crossed polarizers in nuclear flash protection ?

Answer -

The nuclear flash protection system adopted by the French Air Force is neither photochromic devices non crossed polarizers. We chose a permanent filtration system obtained by light-tight superimposed metalic supports. Such a passive filtration is practical against burns and glare and allow for smooth day and night-time flying.

This eliminates the notion of response time to pass from a passive to an active state ; it also eliminates the effect of aging of the systems and the notion of residual phophorescence for the photochromic systems.

The photochromic systems used for eye protection against the luminous and thermal effects of nuclear arms seem to have a limited efficiency due to :

- the very principle of excitation, the exciting energy being intensely proportional to the square of the distance between the observer and the source.
- to the saturation of the photochromic substances which do not permit obtaining a high protection density, even at a short distance from the engine...

These systems are no longer used in the French Air Force.

C) What is the maximum retinal irradiation permitted ?

Answer -

We believe that an irradiance lower than 0.7 cal/cm^2/sec does not cause an irreversible lesion if the exposure time is shorter than 10 sec.

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An exposure of 0.1 Watt/sec/cm^2 (0.1 Joule/cm^2) should be considered as threshold of the absorbed dose.

As far the criterion rise in temperature at the level of the pigmentary epithelium is concerned, the safety threshold seems to be 5°C.

Questions 3 - Colour Vision in Aviation

A) Where do you consider the reduction in color discrimination with age to be ? Is it primarily due to lenticular yellowing or is it retinal ?

Answer -

The deteriorating color discrimination as a function of age seems to be of retinal origin (the lenticular factor plays a secondary role a light reducing factor). In addition, the reduction of the pupillary surface as a function of age can be compared to what happens in therapeutic myosis, it decreases the subject's color perception.

B) Is blue avoided in the French Air Force as a signal color because of foveal tritanopia ?

Answer -

Blue is only used to mark the taxiing runways. These color sources should be large enough to compensate for fovea tritanopia.

2. QUESTIONS ASKED by Generalartz NISSEN to Professor CHEVALERAUD.

Question 1 -

What is best for helicopter pilots who need corrective glasses to avoid glare during hedge-hopping against the sun ?

- colored vizor with plate glasses

or - tinted glasses with a normal vizor ?

Answer -

I believe it is always preferable to wear plate corrective glasses with a colored vizor on demand.

Question 2 - Night vision.

What is the proper attitude in the field of aptitude towards pilots who need pilocarpine since visual acuity is reduced in night-time ?

Answer -

The proper thing to do is to study the repercussions on visual information : acuity (often improved), photopic and mesopic visual field (reduced) and adaptometry.

- If there is no repercussion, normal activity can be maintained except for operational flights with protection vizors.
- If there are repercussions : no flight in single seaters should be allowed ; fighter pilots should turn to commercial aircraft or become pilot instructors ; they should only be allowed to fly in day-time.

3. QUESTIONS ASKED by Maj. MANLIO CARBONI to Professor CHEVALERAUD.

Question 1 -

Regarding the screening criteria defined by NASA for the selection of the future SPACELAB payload specialists, what are the examinations performed by the ophthalmologist ?

Can you give a complete list of these examinations ?

Answer -

There are various types of ophthalmological examinations performed on the payload specialist applicants ;

- clinical examinations :
  - . measure of visual acuity (near and far vision),
  - . measure of refraction,
  - . examination of the fundus after dilatation of the anterior segments,
  - . measure of the ophthalmic arterial pressure,
  - . measure of ocular tonus during aplanation.

- orthoptic examination :
  . study of the extrinsic and intrinsic motility.

- checking of colour vision :
  . Farnsworth 100 hue test with each eye.

- study of the photopic visual field

- study of acuity recovery after glare

- electrophysiological check-up :
  . E.R.G.
  . E.O.G.

4. QUESTION ASKED by Wing Commander A.J. SHEEHAN to Professor BLANC and BORDES.

Question 1 -

Do you consider that there could be a place for routine allergy skin testing in the selection of aircrews ?

Answer - (Pr BLANC)

In France, it is not customary to perform allergy tests in the selection of flying personnel. I believe it would be riseless anyway, as it is difficult to diagnose allergy in the ENT practise.

Answer - (Pr BORDES)

I personnally disagree with Dr BLANC. The tests are not systematically performed and I wish they were. They should be performed to confirm or infirm an allergy diagnosis towards which the ENT examination leads the examiner : discoloration of the nasal pituitary mucous tissue is characteristic (pale, lilac colour). It is slightly edematous, sometimes oozing. Sinus X-ray shows major hyperphasia in characteristic contour. During the interview the subject describes crises of spasmodic coryza or dyspnea generally preceeded by sneezing and clear and abundant rhinorrhea. The blood count shows eosinophilia. Really, in 90 % of the cases, the diagnosis of allergy is relatively easy to deliver in ENT medicine and considering the serious consequences of allergy (rhinitis, sinusitis, baro-traumatic otitis) in flying personnel, I believe that the skin tests should be performed whenever allergy is suspected in the clinical examination.

5. QUESTIONS ASKED by Wing Commander A.J. SHEEHAN to Professor BORDES.

Question 1 -

Do you carry out stapes mobilisation on aircrew with otosclerosis ?

Answer -

Stapes mobilisation is no longer carried out. In any case it involves no risk and can be carried out on flying personnel. However, in the case of otospongiosis, the stapes always freezes again after some time except if the condition has reached a terminal histological stage.

Question 2 -

How long after an ear operation e.g. tympanotomy (or stapedectomy or myringoplasty) would you allow a person to fly as a passenger ?

Answer -

After stapedectomy, unfitness is the rule even for a passenger for a period of 3 to 6 months. After exploration tympanotomy, 21 days only if the middle ear has kept its anatomical integrity. After transtympanic Sheppard's drain, subjects are not unfit for flying. After myringoplasty they are unfit for 1 to 2 month, i.e. time necessary for good scarring. The same rule applies after tympanoplasty, but several cases should be considered.

6. QUESTION ASKED by Lt-Col. Ernesto J. MADEIRA to Professor BORDES.

Question -

How frequently do you observe exostoses of the external acoustic meatus in flying personnel and how do you treat them ?

Answer (Pr BORDES) -

Exostoses of the external acoustic meatus are actually frequent in flying personnel as they are in divers or swimmers. It is probably due to a defense mechanism of the duct against a thermal or baro-traumatic stress. The treatment is simple;it consists in surgical exeresis with a drill rather than with a gauge as this latter type of surgery may cause a fracture propagating to the tegmen tempani or to the middle ear.

PROGRAMME OF THE FIFTH ADVANCED OPERATIONAL AVIATION MEDICINE COURSE

ECOLE D'APPLICATION DU SERVICE DE SANTE POUR L'ARMEE DE L'AIR

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5 bis, Avenue de la Porte de Sèvres - 75015 PARIS, FRANCE

12-23 September 1977

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. Color vision in aviation . Practical demonstration of color vision testing . Vision at low luminance levels in aviation . Glare and its adverse consequences in aviation	Médecin en Chef CHEVALERAUD
. Practical demonstration of light sense and glare resistance testing . Depth vision and aviation . Visual problems raised by low altitude high speed flight	Médecin en Chef MANENT
. Practical demonstration of depth vision testing . The contribution of electrophysiology in the selection and ophthalmological surveillance of flying personnel . Practical demonstration of electro-physiology techniques applied to flying personnel selection and surveillance	Médecin en Chef CHEVALERAUD

AVIATION OTO-RHINO-LARYNGOLOGY

. Auditory information of flying personnel	Médecin en Chef BORDES

. Aviator hearing loss . Practical demonstration of auditory selection techniques for flying personnel	Médecin en Chef BLANC
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. New aspects of barotraumania O.R.L.	Médecin en Chef BORDES
. Nose pathology of the flying personnel	Médecin en Chef BLANC
. Visit of the Aerospace Medical Laboratory of the Flight Test Center of Bretigny-sur-Orge	Médecin en Chef AUFFRET
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. Visit of Versailles Castle	
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. Practical problems raised by oto-rhino-laryngology standards	Médecin en Chef BLANC
. Round-table with the lecturers	
. Conclusions	Médecin Général PERDRIEL

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14. Abstract

This Report contains all the lectures delivered to the Course, which dealt with the selection procedures and performance standards applied to flying personnel in respect of ophthalmology and oto-rhino-laryngology.

Visual, auditory, and vestibular fitness standards have to be sufficiently well specified to ensure that flying personnel, in the course of their duties, are able to perform functions which, in many cases, are becoming increasingly complex and difficult.

Medical examinations of flying personnel undertaken at examination centres must use precise and reliable techniques to assess flight fitness.

The Course was conducted under the auspices of the Aerospace Medical Panel of AGARD.

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